

PERFORMANCE EVALUATION OF SIGNALIZED INTERSECTION AT AREA D USING VISSIM MICROSIMULATION AND HCM 2010

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Abstract: Traffic performance in a road network is significantly influenced by traffic flow at intersections. Area D, a signalized intersection located in Dodoma City, Tanzania experiences traffic congestion during peak hours, causing excessive vehicle delays when signals are in operation. The main objective of the study is to evaluate traffic performance of the existing intersection using Highway Capacity Manual (HCM 2010) and PTV VISSIM simulation during peak periods. Vehicle flow was measured during morning and evening peak periods, specifically at 06:00 to 10:00 AM and from 04:00 to 06:00 PM. The traffic composition during the morning peak consisted of light vehicles (46.95%), motorcycles (33.78%), and heavy vehicles (19.27%), while during the evening peak it consisted of light vehicles (46.46%), motorcycles (36.06%), and heavy vehicles (17.48%). Analysis using HCM 2010 indicated that the average delay was 55.16 sec/pcu during the morning peak and 115.14 sec/pcu during the evening peak. The average queue lengths were 131.2 m and 327.4 m, with Level of Service E and F during morning and evening peak hours, respectively. PTV VISSIM Version 11 results showed higher delays of 99.67 sec/pcu and 149.14 sec/pcu. Three improvement scenarios were evaluated using a micro-simulation approach. The third scenario, combining traffic signal optimization and geometric improvements, was identified as the most effective. This scenario reduced delays to 21.27 sec/pcu and 29.86 sec/pcu, decreased queue lengths to 29.86 m and 89.45 m, and improved level of service to B and C during morning and evening peak hours.

Keywords: traffic performance, signalized intersection, US HCM 2010, PTV VISSIM.

Abstrak: Kinerja lalu lintas pada suatu jaringan jalan sangat dipengaruhi oleh arus lalu lintas di persimpangan. Area D, sebuah simpang bersinyal yang terletak di Kota Dodoma, Tanzania, mengalami kemacetan lalu lintas pada jam-jam puncak yang menyebabkan keterlambatan kendaraan yang tinggi saat sinyal beroperasi. Tujuan utama penelitian ini adalah untuk mengevaluasi kinerja lalu lintas simpang eksisting menggunakan metode Highway Capacity Manual (HCM 2010) dan simulasi PTV VISSIM selama periode jam puncak. Arus kendaraan diukur pada periode puncak pagi dan sore, yaitu pukul 06.00–10.00 dan 4.00–6.00. Komposisi lalu lintas pada jam puncak pagi terdiri dari kendaraan ringan (46,95%), sepeda motor (33,78%), dan kendaraan berat (19,27%), sedangkan pada jam puncak sore terdiri dari kendaraan ringan (46,46%), sepeda motor (36,06%), dan kendaraan berat (17,48%). Hasil analisis menggunakan HCM 2010 menunjukkan bahwa tundaan rata-rata sebesar 55,16 det/kend pada jam puncak pagi dan 115,14 det/kend pada jam puncak sore. Panjang antrian rata-rata masing-masing adalah 131,2 m dan 327,4 m, dengan Tingkat Pelayanan (Level of Service/LOS) E dan F pada jam puncak pagi dan sore. Hasil simulasi PTV VISSIM versi 11 menunjukkan tundaan yang lebih tinggi, yaitu 99,67 detik/pcu dan 149,14 detik/pcu. Tiga skenario perbaikan dievaluasi menggunakan pendekatan mikrosimulasi. Skenario ketiga, yang menggabungkan optimasi sinyal lalu lintas dan perbaikan geometrik, diidentifikasi sebagai yang paling efektif. Skenario ini mampu menurunkan tundaan menjadi 21,27 det/kend dan 29,86 det/kend, mengurangi panjang antrian menjadi 29,86 m dan 89,45 m, serta meningkatkan Tingkat Pelayanan (LOS) menjadi B dan C pada jam puncak pagi dan sore.

Kata kunci: kinerja lalu lintas, persimpangan bersinyal, HCM 2010, PTV VISSIM

1. INTRODUCTION

The uneven distribution of traffic flow between approaches and limited space at the intersection causing long queue, significant delay and even congestion during the peak hours. This conditions not only affects travel time for road user, but also overall operational performance of this intersection. Therefore, a comprehensive evaluation of the operational performance of this intersection is needed in order to formulate data driven and realistically applicable solutions. In the US Highway Capacity Manual 2010 are the main reference for evaluating the capacity and performance of signalized intersections. High-way Capacity Manual 2010 provides an analytical approach based on traffic condition, with parameters such as capacity, degree of saturation, average delay, queue length and level of service (HCM 2010).

Level of Service is categorized into six grades, ranging from A to F, where A represents the most favorable traffic conditions and F indicates the poorest operating conditions. (Dağlı et al., 2024). Parameters are used as an average indicator of average speed, delay, travel time, operating conditions, and road safety in the traffic flow. In one study, The factors influencing control delay one of the key performance measures at signalized intersections were examined, and the concept of average control delay was established (Darma et al., 2005). Signal timing and geometric design are also commonly examined in the literature. The reviewed studies highlight the development of systems that adapt dynamically traffic volume at intersections and optimize signal timing through the use of real-time data. (Chen & Wu, 2025). The capacity of road intersections is a key constraint and plays a critical role in determining the overall performance of road networks. (Fourati. W, & Friedrich. B, 2019). Furthermore, enhancements of the performance indicators such as vehicle delay, level of service, and fuel consumption were achieved by optimizing the existing signal timings. (Elefteriadou Transportation Research Board, 2016). Methods based on the Highway Capacity Manual apply techniques such as multiple linear regression and sensitivity analysis to evaluate the degree of saturation under mixed traffic conditions. In this context, a regression model has been developed to estimate saturation flow for such condition (Darshan et al., 2018).

The saturation flow rate has been determined using various methods, including those outlined in the Highway Capacity Manual 2000. Additionally, several studies have proposed modifications to these methods based on their research, particularly to better suit conditions in developing countries. (Krupesh et al., 2015)

As a complementary approach, microscopic simulation using software such as VISSIM is becoming increasingly popular in traffic research. VISSIM can model individual vehicle behavior based on geometric conditions and real traffic volume data, thereby capturing the complexity of traffic interactions in a more realistic manner. (Shahdah et al., 2015), (Zakariah et al., 2025). The primary advantage of PTV VISSIM is its ability to simulate various operational scenarios without interrupting real-world traffic conditions, while also providing detailed visualization of traffic flow patterns. As a result, microscopic simulation tools like VISSIM have become increasingly popular in traffic research, as they can realistically represent individual vehicle behavior based on geometric features and actual traffic volumes. At signalized intersections, delay represents the time loss encountered by vehicles due to influencing factors such as road geometry, demand levels, and signal control operations. Inefficient signal timing, along with inadequate geometric design, can reduce intersection capacity and lead to increased delays. (Potts et al., 2007).

Geometric characteristics of intersections play a vital role and must be considered when evaluating the performance of signalized intersections. Research by (Iin et al. 2024) indicates that the physical design of intersections such as the number of lanes, approach length, turning radius, and the presence of direct turning movements significantly influences both capacity and delay. In the case of the Area D Intersection, variations in geometric design among approaches, combined with a high volume of right-turn movements, highlight the importance of evaluating performance using actual geometric conditions through simulation with PTV VISSIM. High and uneven traffic volumes across

different approaches also pose a significant challenge in optimizing signal timing. References (Purwanto et al., 2023), (Zulfhazli et al., 2021) found that an increase in vehicle volume on one approach, without corresponding adjustments to signal timing, can lead to substantial delays and localized congestion. In developing a transportation model, it is essential to ensure that the simulation accurately reflects real-world conditions; therefore, a validation process should be carried out by comparing observed traffic volumes in the field with the results produced by the simulation. (Mira et al., 2025).

2. RESEARCH METHODS

Research design

This research began with literature studies, problem identification and study location determination. Then, followed by data collection through field surveys. After that, followed by performance analysis which was carried out using the US HCM 2010 method and microscopic simulation modeling using VISSIM software. The results of these two approaches were analyzed comparatively to produce conclusion and recommendations.

Data collection

Data collection was conducted directly in the field using three main methods:

1. Geometric Intersection survey, which include measuring the number of lanes, approach length, lane width, turning radius and other relevant physical data.
2. Traffic counting survey, conducted manually using video record to obtain vehicle volume data at each approach based on morning and evening peak hours. Data collected in units of vehicles/hour and grouped by vehicle type (light vehicle, heavy vehicles and motorcycles).
3. Signal phase survey.

Data Analysis

Data analysis was conducted using two approaches:

1. Performance calculation using US HCM 2010. In this approach, the parameters used includes:
 - Capacity, volume, degree of saturation (DS), average delay, queue length and level of service (LOS)

- Parameters are evaluated for each approach and compared with the thresholds according to US HCM 2010.

2. Simulation Using PTV VISSIM

- The intersection model was built according to the actual geometric conditions based on the survey results.
- Traffic volume was entered as input into the simulation model.
- Calibration was performed by comparing simulation result with field data.
- Scenario simulations are performed to test the possible improvements such as signal time redistribution.

The results of both the US HCM 2010 and VISSIM approaches are analyzed comparatively to see the differences in the result an effectiveness of each method in evaluating intersection performance. Simulation results are also used to identify potential operational improvement.

Study area

This study was conducted at the Area D Intersection in Dodoma City. The intersection is a signalized three way intersection connecting

1. Dar es Salaam – Dodoma Road (east approach)
2. Dodoma – Dar es Salaam Road (west approach)
3. Emaus Road (north approach)

This location was chosen because is the one of the intersections with high traffic volume in Dodoma City and it serves as the main link between Dar es Salaam main port and Southern and East African countries and also residential and commercial areas.



Figure 1. Study Area (Source: Google Maps)

3. RESULTS AND DISCUSSION

Traffic flow at area D intersection.

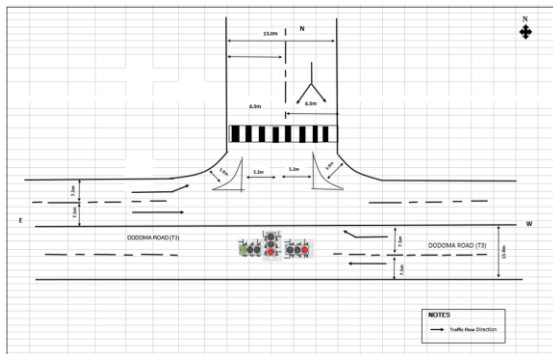


Figure 2. Intersection Geometry

The area D intersection is a three-leg signalized intersection that connects three main roads in Dodoma City, namely, Dar es Salaam – Dodoma Road on east side, Dodoma – Dar es Salaam Road on west side and Emaus Road on North side. Each approach has a different geometric configuration, which affects the capacity and operational of the intersection. The East approach (Dar es Salaam – Dodoma Road) consists of the two entry lanes with a total effective width of 7.5 meters and two exit lanes with the width of 6.5 meters, while the left turn lane (LT) is 5.8 meters. The West approach (Dodoma - Dar es Salaam Road) consist of the two entry lanes with a total effective width of 7.5 meters and two exit lanes with the width of 6.5 meters, while the left turn lane (LT) is 5.8 meters. The North approach (Emaus Road) consist of the two approach lanes with a total effective width of 6.5 meters and one exit lanes right turn (LT) with the width of 5.2 meters, while the left turn lane (LT) is 5.8 meters.

Table 1. Intersection Geometric Data

Approach	Approach Width-WA(m)	Width Entry-Wentry(m)	Width Exist-W exist(m)	Width-LTOR(m)	Number of Lane	
					Entry	Exist
Dodoma-East	7.5	6.5	6.5	5.8	2	2
Dodoma-West	7.5	6.5	6.5	N/A	2	2
Emaus-South	6.5	5.2	5.8	5.8	1	1

Traffic Signal setting at the Area D intersection use three phase signal with customized time distribution for each approach based on the traffic volume and characteristics. The existing signal time for the morning peak hour has a total cycle time of 363 seconds and the yellow time is 3 seconds for both phases. Where phase 1 is for Eastern Approach, the green time is about 165 seconds and the total red time is about 193 seconds. Phase 2 for Western approach, the green time is about 125 seconds and the total red time is about 363seconds. For Phase 3 consist of Northern approach the green time is about 58 seconds and the total red time is about 300 seconds which is the highest among these three phases.

Table 2. Existing Signal Phase Times – Morning Peak Hours

Approach	Phasing	Red(sec)	Signal Timing			Cycle Time (sec)
			Yellow(sec)	Green(sec)	All Red(sec)	
East	Phase 1	193	3	165	2	363
West	Phase 2	233	3	125	2	363
North	Phase 3	300	3	58	2	363

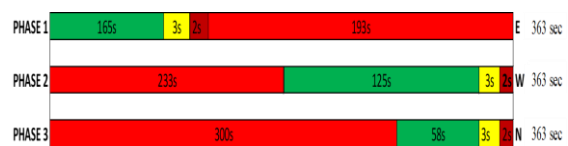


Figure 3. Existing Signal Time Diagram – Morning Peak Hours

The existing signal time for the evening peak hour has a total cycle time of 332 seconds and the yellow time is 3 seconds for both phases. Where phase 1 is for Eastern Approach, the green time is about 135 seconds and the total red time is about 192 seconds. Phase 2 for Western approach, the green time is about 125 seconds and the total red time is about 202 seconds. For Phase 3 consist of

Northern approach the green time is about 57 seconds and the total red time is about 270 seconds which is the highest among these three phases.

Table 3. Existing Signal Phase Times – Evening Peak Hours

Approach	Phasing	Signal Timing				Cycle Time (sec)
		Red(sec)	Yellow(sec)	Green(sec)	All Red(sec)	
East	Phase 1	192	3	135	2	332
West	Phase 2	202	3	125	2	332
North	Phase 3	270	3	57	2	332

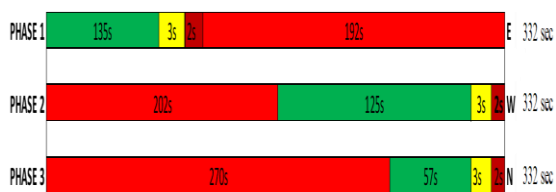


Figure 4. Existing Signal Time Diagram – Evening Peak Hours

The traffic counts survey was conducted at the Area D intersection along the Dodoma Trunk Road (T3) – Emaus Road for four hours in the morning session starting from 6:00 am – 10:00am and two hours in the evening session starting from 4:00 pm - 6:00 pm at the 15 – minute intervals during weekdays using a high- definition hand camera. Traffic count were conducted on Tuesday, March 10, 2026. During morning and evening peak hours. The peak hour was determined by finding the highest total volume within a 15 – minute period. During the traffic count, the number of vehicles such as Light Vehicles (LV), Heavy vehicles (HV) and Motorcycle (MC) was recorded based on each direction. The large number of Light Vehicle observed during the traffic count in this intersection approach made the intersection oversaturated while waiting for the green time.

Table 4 below, shows that traffic data with the peak hour during morning occurred between 06:30AM – 07:30AM with the maximum highest traffic of 2,457 vehicles/hour passing through the intersection. Therefore, the traffic flow at this peak hour was selected as the basis for performance analysis. The reason for this is that this period recorded the highest volume of all survey data, thus representing the worst-case scenario in terms of traffic performance at the research location. By using these peak conditions, the performance

evaluation will be more comprehensive and able to illustrate the capacity of the intersection when maximum traffic load occurs.

Table 4. Traffic Flow Vehicles for each approach during Morning Peak Hours

Approach	Traffic Movement	Light Vehicles (veh/hour)	Heavy Vehicles (veh/hour)	Motorcycle (veh/hour)	Total Vehicles (veh/hour)
North	LT/LTOR	131	56	107	294
	RT	198	35	114	347
	TOTAL	329	91	221	641
East	LT/LTOR	105	3	94	202
	ST	292	180	234	706
	TOTAL	397	183	328	908
West	ST	321	200	204	725
	RT	95	13	75	183
	TOTAL	416	213	279	908
Total Motor Vehicles					2,457

Table 5. Proportional of the Vehicles at Area D Intersection during Morning Peak Hours

APPROACH	TOTALVEHICLES PER APPROACH (Veh/hour)			VEHICLES PROPORTIONAL (%)		
	LV	HV	MC	LV	HV	MC
North	329	91	221	51.33	14.20	34.48
East	397	183	328	43.72	20.15	36.12
West	416	213	279	45.81	23.46	30.73

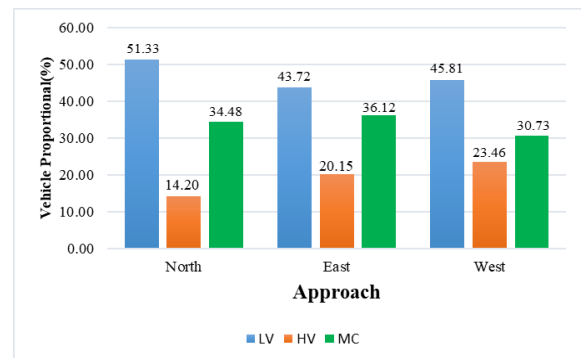


Figure 5. Proportional of the Vehicles at Area D Intersection during Morning Peak Hours

Figure 5 above, shows the traffic proportion during morning peak hours at this intersection. The North Approach is dominated by Light Vehicles (51.33%), Motorcycles (34.48%) and Heavy Vehicles (14.20%). The East Approach is dominated by Light Vehicles (43.72%), Motorcycles (36.12%) and Heavy Vehicles (20.15%) and the West Approach is dominated by Light Vehicles (45.81%), Motorcycles (30.73%) and Heavy Vehicles (23.46%).

Table 6. Traffic Flow Vehicles for each approach during Evening Peak Hours

Approach	Traffic Movement	Light Vehicles (veh/hour)	Heavy Vehicles (veh/hour)	Motorcycle (veh/hour)	Total Vehicles (veh/hour)
North	LT/LTOR	277	100	208	585
	RT	230	54	198	482
	TOTAL	507	154	406	1067
East	LT/LTOR	187	53	185	425
	ST	472	179	300	951
	TOTAL	659	232	485	1376
	ST	345	256	352	953
	RT	190	49	160	399
	TOTAL	535	305	512	1352
Total Motor Vehicles					3,795

Table 7. Proportional of the Vehicles at Area D Intersection during Evening Peak Hours

APPROACH	TOTAL VEHICLES PER APPROACH (Veh/hour)			VEHICLES PROPORTIONAL (%)		
	LV	HV	MC	LV	HV	MC
North	507	154	406	47.52	14.43	38.05
East	659	232	485	47.89	16.86	35.25
West	535	305	512	39.57	22.56	37.87

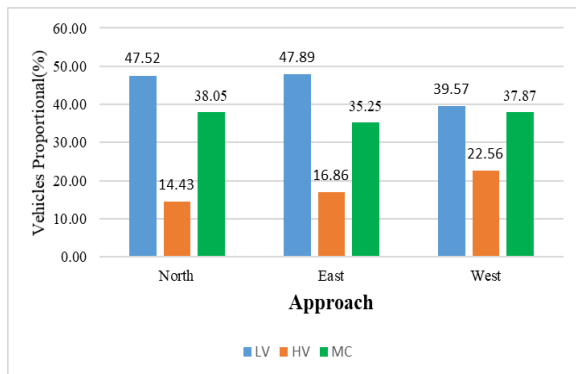


Figure 6. Proportional of the Vehicles at Area D Intersection during Evening Peak Hours

Figure 6 above, shows the traffic proportion during evening peak hours at this intersection. The North Approach is dominated by Light Vehicles (47.52%), Motorcycles (38.05%) and Heavy Vehicles (14.43%). The East Approach is dominated by Light Vehicles (52.30%), Motorcycles (32.27%) and Heavy Vehicles (15.44%) and the West Approach is dominated by Light Vehicles (39.57%), Motorcycles (37.87%) and Heavy Vehicles (22.56%).

Existing condition based on HCM 2010

Table 8. Existing Service Level Conditions at the Area D Intersection

Period	Approach	V/C Ratio			Approach Delay(D) (sec/pcu)	LOS	Average Intersection Delay (sec/ pcu)
		LT	ST	RT			
Morning Peak Hour	North	0.969	-	1.000	123.3	D	55.162
	East	0.158	0.927	-	1.0		
	West	-	0.397	0.228	16.2		
Evening Peak Hour	North	2.289	-	0.406	415.774	F	115.14
	East	0.588	0.435	-	7.492		
	West	-	0.506	0.158	14.350		

Table 8 above, shows the analytical result is based on the existing geometric condition to determine the traffic performance of signalized intersection. The v/c ratio is determined based on the lane group, where for the morning peak hours, the East approach has higher v/c ratio of approximately 0.927 for straight turn and 0.158 for left turns. The West approach has the lowest v/c ratio of approximately 0.397 for straight turn and right turn of approximately 0.228 during the morning peak hour time. However, the evening peak hour, the westbound approach has the highest v/c ratio of approximately 0.506 for the through and 0.158 for the right turns. The east bound approach has the lowest v/c of approximately 0.588 for the through and 0.435 for the right turns during the evening peak hours. Therefore, based on the US HCM, the v/c ratio is ≥ 1.0 for the intersection approaches indicating that overall signal timing and geometric design provide inadequate capacity for the given demand flow.

Then from the above results based on the geometric of the existing signalized intersection, it shows that average delay of the intersection during the morning peak hour is about 55.162 sec/pcu, so based on this result the intersection level of service during morning peak hour is E. For the evening peak hours, results show that the average intersection delay is about 115.14 sec/pcu which is level of service F. The delay is caused by random stops and drops near intersection approach which implies blockage of other vehicles. Therefore, based on US HCM the Intersection that has LOS F is considered unacceptable to driver because arrival rate is greater than existing intersection capacity.

Result of the microscopic simulation using PTV VISSIM

In developing a transportation model, the suitability of the simulation model with real conditions, a validation process was carried out using the GEH (Godfrey E. Havers Statistic) test. This was based on a comparison between the traffic volume in the field and simulation results

Table 9. GEH Validation

Period	No.	Approach	Field Volume (Vehicle/Hour)	Vissim Volume (Veh/Hour)	GEH	Note
Morning Peak Hour	1	North	641	604	1.483	OK
	2	East	1012	1138	3.843	OK
	3	West	908	1014	3.419	OK
Evening Peak Hour	1	North	1067	959	3.393	OK
	2	East	1503	1351	4.024	OK
	3	West	1352	1198	4.313	OK

Based on Table 9, it shows that the comparison between field traffic data volume and simulation results obtained GEH values for intersection leg below the thresholds value of 5. This indicates that the simulation model used is valid and reliable for further analysis.

Table 10. VISSIM Result for Delay and Queue Length at Existing Area D Intersection

Approach	Delay (sec/pcu)		Queue Length (m)	
	Morning	Evening	Morning	Evening
North	95.74	95.43	103.9	287.94
East	64.73	124.81	134.80	336.80
West	99.04	148.14	154.8	381.56
Intersection Average	99.67	149.14	131.2	327.4

Table 10 above, shows that conditions in the Vissim Microscopic simulation, the results show that the eastern approach to the existing signalized intersection during the evening peak hour has the highest delay of approximately 148.14 sec/pcu. For the evening peak hours, the results show that the Western approach experiences the highest amount of delay of approximately 99.67sec/pcu and 149.46 sec/pcu during morning and evening peak hours respectively. The above results, it can be seen that the longest cycle length plays a significant role in increasing the queue length to the intersection. The average Queue Length with highest value occurs during evening peak hours about 327.4 meters while during Morning Peak hours was 131.2 meters. Therefore, existing intersection delays and Queue Length should be

optimized to improve the capacity and performance of the evening delays and vehicle delays at the intersection during morning peak hours.

Comparison, improvement of results and recommendations

The comparison of the existing signalized intersection results is based on two methods, namely the analytical method using US HCM 2010 and micro- analytical using PTV VISSIM.

Table 11. Comparison of Average Delay for Existing Signalized Intersection

Methods	Delay (sec/pcu)	
	Morning Peak Hour	Evening Peak Hour
US HCM 2010	55.16	115.14
PTV VISSIM	99.67	149.14

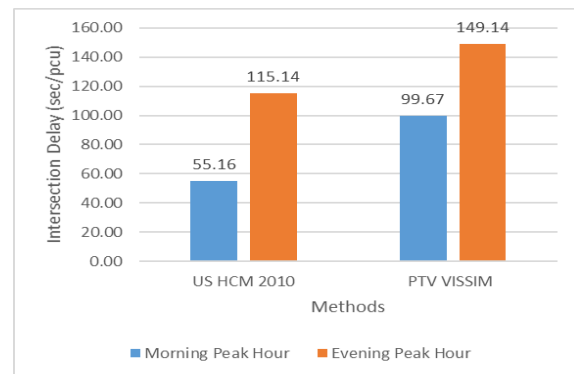


Figure 7. Comparison of Average Delay

Table 11 above, shows the average intersection delay based on US HCM 2010 seems to be low compared to Microsimulation using PTV VISSIM 11 where the intersection delay during morning peak hour is around 55.16 sec/pcu compared to US HCM 2010 which during the during the morning peak hour is around 99.67 sec/pcu. For the evening peak hour, the intersection delay is around 115.14 sec/pcu based on US HCM 2010 compared to PTV VISSIM which is 149.14 sec/pcu. However, the intersection delay differs from the methods because US HCM 2010 the delay

model is developed based on cars dominating the traffic conditions where vehicle follow disciplined lanes. For PTV VISSIM delays are measured based on deceleration from approach cruising speed to approach negotiation speed and acceleration to exit from cruising speed.

In this study, three management scenarios using microsimulation are recommended including:

1. Scenario 1 involves the Signal Setup Optimization
2. Scenario 2 involves Geometric Improvement
3. Scenario 3 involves combination of Signal setup Optimization and Geometric Improvement.

Figure 8 shows the simulation result for scenario 3 (4 phases – phase 1 and phase Combined), where cycle simplification was able to reduce the average delay. The green time was divided by proportionally by giving 150 seconds to Dodoma Road (East), 40 seconds for Emaus Road (North-East), 105 seconds to Dodoma Road (West) and 43 seconds for Emaus Road (North)

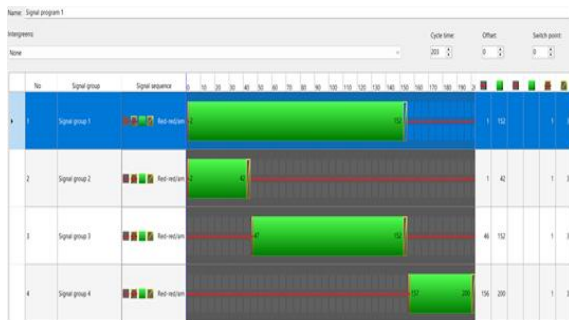


Figure 8. Signal Time Diagram Scenario 3

Table 12. VISSIM Scenario Simulation Results

Junction	Scenario	Duration	Level of Service (LOS)	Average Delay (seconds)	Average Queue Length (meter)	
Area D Intersection, Dodoma City	Existing	Morning	4.427	D	99.67	131.2
		Evening	5.06	E	149.49	327.4
	Scenario 1 Traffic Signal optimization	Morning	2.903	C	33.86	82.22
		Evening	4.482	D	126.01	207.3
	Scenario 2 Geometric Improvement	Morning	4.034	D	68.37	94.25
		Evening	4.981	E	126.01	296.6
	Scenario 3 Traffic Signal Optimization + Geometric Improvement	Morning	2.42	B	21.27	26.88
		Evening	2.95	C	29.86	89.45

Based on Table 12, scenario 1 shows that during Evening the longest average delay occurring at 126.01 seconds with longest queue of 327.4 meter and LOS is D. compared with morning average delay occurring at 33.86 seconds with longest queue

of 82.22 meter and LOS is E. Scenario 2 shows that during Evening the longest average delay occurring at 126.01 seconds with longest queue of 296.6 meter and LOS is E. compared with morning average delay occurring at 68.37 seconds with longest queue of 94.25 meter and LOS is D. Scenario 3 shows that during Evening the longest average delay occurring at 29.86 seconds with longest queue of 89.45 meter and LOS is C. compared with morning average delay occurring at 21.27 seconds with longest queue of 89.45 meter and LOS is B. Based on a comparison of the simulated scenario results, scenario 3 is considered the most effective alternative because it is able to reduce average delay. Therefore, it is recommended as the main strategy for handling the Area D Intersection at Dodoma City.

4. CONCLUSION

Based on the analysis results, it can be concluded that:

1. The Existing condition of the Area D Intersection is at service level E with an average delay of between 99.67 and 149.49 seconds and maximum queue length of 327.4 meters (evening peak hours).
2. The VISSIM modelling results have been well validated (GEH value < 5), therefore can be used for testing improvement scenario.
3. Regarding improvement, three improvement scenarios were evaluated. Scenario 3 (4 phases – phase 1 and phase Combined), is the most effective alternative, as it is able to reduce average delays and queue lengths more evenly than other scenarios

5. AUTHOR CONTRIBUTIONS

Author have contributed equally to all stages of the preparation of the manuscript and have read and agreed to the published version.

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