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Operational Analysis and Capacity Improvement Strategies for Signalized Intersections: Case Study on Miami, Florida

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Abstract

The expansion of population and economic activities within urban settings has driven a surge in demand for diverse transportation modes leading to higher traffic volumes, increased probability of congestion due to spillback, and reduced Level of Service (LOS). To reduce that probability, studying signalized intersections is essential as they play a pivotal role in alleviating congestion by reducing delay, increasing traffic flow efficiency, and ensuring safety. This study investigates a congested intersection in Miami, Florida, USA, employing Highway Capacity Software (HCS) to evaluate operational performance. While geographically specific, the methodology is believed to be highly applicable to similar urban settings, where signalized intersections frequently face similar demand-supply mismatches. The analysis revealed severe delays, high queue spillbacks, and a LOS F during peak hours. Two data-driven scenarios were evaluated: (1) optimization of signal timing and (2) integration of a grade-separated pedestrian bridge with signal timing optimization. The combined implementation of the pedestrian bridge and optimized signal timing achieved nearly 53% reduction in delays and improved the intersection's performance from LOS F to LOS E.

Keywords: signalized intersections; spillback; level of service (LOS); Highway Capacity Software (HCS7); operational performance

1. Introduction

In a transportation network, intersections are a critical component, as they significantly influence the overall performance of traffic flow and capacity [1]. Although there are different types of intersections, including signalized and unsignalized, studying signalized intersections is particularly crucial due to the significant emphasis on regulating traffic flow, determining the Level of Service (LOS), optimizing network capacity, and mitigating congestion [2]. Ensuring efficient traffic flow and maintaining road safety involves drawbacks both for road users and society as a whole including operational and maintenance expenses, longer delays, and higher fuel consumption [3]. Furthermore, complex and unpredictable vehicle and pedestrian behaviors make it challenging to assess the LOS, thus, to effectively plan and increase efficiency, it is essential to understand the patterns and characteristics of both vehicle and pedestrian traffic [4]. Tools such as HCS, Synchro, CORSIM, SIDRA, SUMO, Vissim, and Aimsun enable detailed evaluations of intersection capacity and delay

under various scenarios with visualization [5]. However, a research gap remains in literature regarding in-depth operational analyses and improvement strategies tailored to Florida's unique urban traffic conditions. Florida's subtropical climate, high tourist activity, and growing population contribute to distinctive traffic flow patterns and congestion issues that may not be addressed adequately by general traffic models or improvement strategies developed elsewhere. Furthermore, according to research by a specialized company, Miami is ranked 9th with the worst traffic globally and 5th in the USA [6]. Additionally, the lack of context-sensitive research highlights the need for a data-driven framework that evaluates improvement strategies while assessing their applicability to intersections that deal with heavy traffic flow from a global perspective. Thus, this study aims to bridge that gap by presenting a detailed operational analysis of a signalized intersection in Miami and evaluating the effectiveness of targeted capacity improvement strategies.

The findings aim to inform local traffic management strategies and guide future studies in similar urban settings facing congestion and having poorer LOS. The primary objective of this project is to assess the intersection's operational performance during the PM peak-15-minute period and propose signal timing improvements to mitigate spillbacks, particularly in the context of the 95th percentile queue storage ratio. The analysis was conducted using Highway Capacity Software 7 (HCS7), a widely used tool for evaluating the performance of signalized intersections that incorporate various modules and submodules based on the procedures and methodologies outlined in the Highway Capacity Manual (HCM) with basic parameters and inputs [7]. The selected intersection is controlled by traffic signal and supports multiple traffic movements, including left-turn, through, right turn, along with pedestrian crossings, all of which impact regular traffic flow. The study evaluates the existing traffic flow based on a three-day average of vehicle and pedestrian counts during the PM peak (5:15 PM to 5:30 PM). Traffic conditions, including vehicle types (with 3% heavy vehicles) and arrival types (Arrival Type 4 for East-West through movements and Arrival Type 3 for other movements), are considered to simulate realistic traffic behavior. This research provides an in-depth assessment of the intersection's capacity and proposes signal timing adjustments that could improve its performance by reducing spillbacks and improving overall traffic flow, which can be adopted anywhere with a similar context.

The main goal of this research is to improve the operational performance of a congested signalized intersection. To achieve this goal, three key objectives have been defined. First, to assess the existing traffic conditions at the intersection by analyzing the traffic flow during the PM peak period, evaluating traffic volume and signal timings, and determining the Queue Storage Ratio (RQ) for all movements to identify areas of spillbacks using HCS7. Second, to identify spillbacks for critical movements, including left-turn, through, and right-turn movements, by utilizing the 95th percentile. Third, propose improvements to signal timings, considering pedestrian-related delays based on the spillback analysis, aiming to reduce the RQ and enhance intersection performance.

Study Area Profile

In recent decades, significant amount of research has been conducted to evaluate the operational and safety performances of signalized intersections and roundabouts in various countries [8]. Research on signalized intersections has focused on several factors such as delay time, signal duration, and traffic management systems, demonstrating improvements in traffic flow, delays, safety, and environmental impacts. This emphasizes the need to optimize four-legged intersections [9]. Considering the parameters that affect the operational performance, this study presents a detailed capacity analysis of the intersection at SW 109th Avenue and SW 8th Street in Miami, Florida, USA, near the Modesto main campus of Florida International University. experiences high traffic volumes and regular peak-hour congestion. Its geometry consists of several through lanes, dedicated left-turn and right-turn lanes, and standard signal phases. Traffic counts, signal timings, and geometric information were gathered through field surveys and secondary data sources. The satellite image of the intersection is shown in Figure 1.
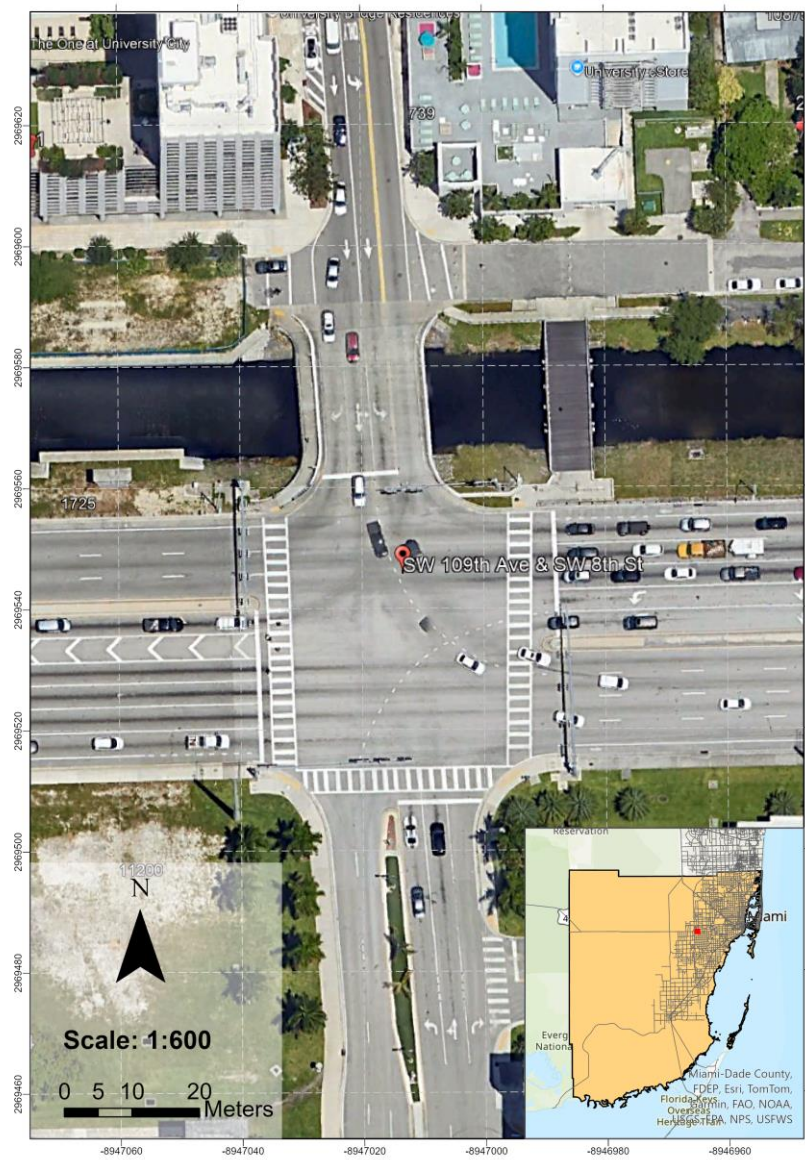
Figure 1. Geometric condition of the intersection (Source: Google Earth, 2025).

2. Materials and Methods

The proposed methodology is divided into four stages to improve persisting traffic conditions. Comprehensive traffic data regarding geometry, signal timing, and traffic volume is an essential part of any traffic analysis for making informed decisions [10]. The data used to analyze the intersection has been obtained from multiple platforms and resources. These data sets have been utilized to provide input parameters to evaluate the intersection's capacity and create improvement scenarios for analysis with HCS7. HCS7 is a widely recognized and comprehensive traffic analysis tool that incorporates all the required modules based on the procedures and methods outlined in the HCM (7th edition). Considering the basic parameters and inputs, this tool has the ability to quickly and efficiently analyze traffic operation, optimize the signalized intersection performance by reducing delays and queue lengths by adjusting in-cycle times [7]. Figure 2 illustrates the proposed research methodology to improve the LOS and reduce traffic delays of the intersection.
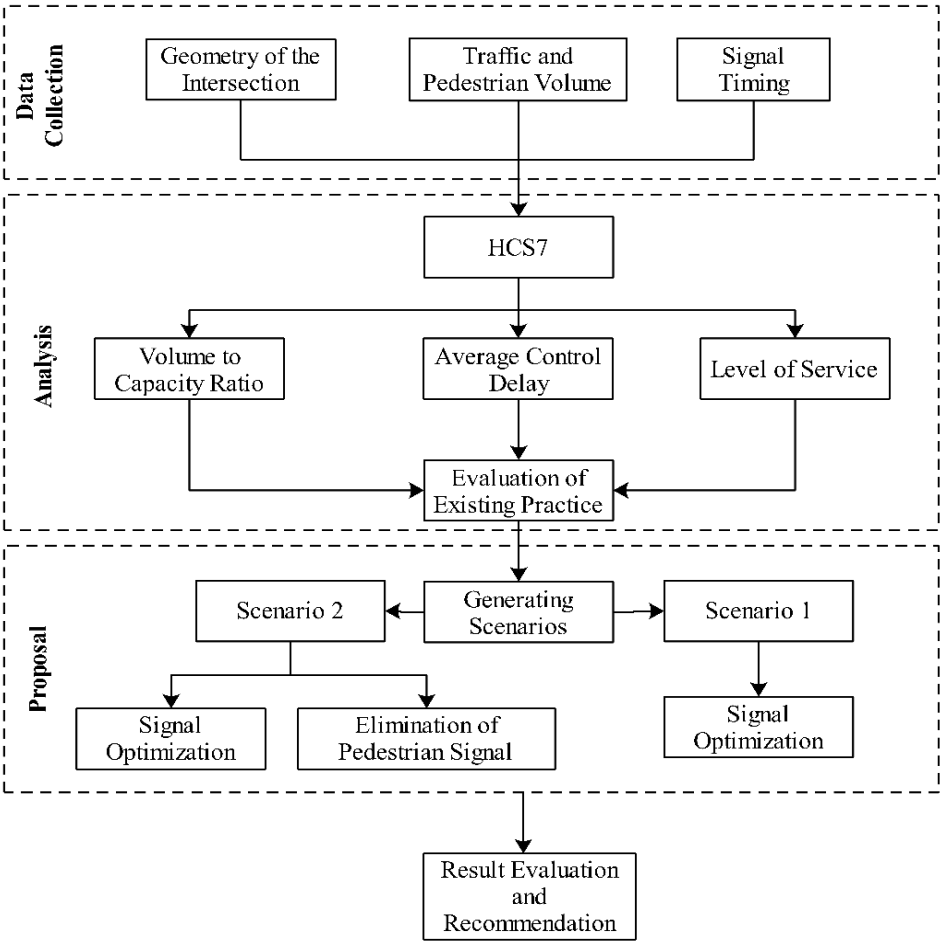
Figure 2. Research Methodology. Source: Author, 2025.

2.1. Traffic Volume

The geometric conditions of the intersection have been obtained from Google Maps and field surveys and are shown in Figure 1. This geometric data has been crucial for understanding the intersection's capacity and performance. The following key parameters have been considered. The storage lengths (in ft.) for all left-turn lanes, through lanes, and right-turn lanes, and the average width of each lane (in ft.) in the Eastbound (EB), Westbound (WB), Northbound (NB), and Southbound (SB) directions have been measured and summarized in Table 1.

Table 1. Storage Lengths and Lane Width of the Intersection.

Storage Length of Lanes											
Eastbound			Westbound			Northbound			Southbound		
Left	Thru	Right	Left	Thru	Right	Left	Thru	Right	Left	Thru	Right
550	1121	-	267	1113	-	456	456	190	243	376	114
Width of Lanes											
Eastbound			Westbound			Northbound			Southbound		
Left	Thru	Right	Left	Thru	Right	Left	Thru	Right	Left	Thru	Right
10.6	11	-	11	11	-	11	11	11	11	11	11

"- " indicates there is no Right Turn movement in that direction. Source: Field survey, 2025.

Traffic volume data was based on three-day average counts for vehicles and pedestrians during the PM peak of the 15 minutes. The peak period specifically considered is between 5:15 PM and 5:30 PM. To convert the 15-minute interval counts into vehicles per hour (veh/h), the raw data has been multiplied by a factor of 4. The resulting flow rates for each movement are detailed in Table 2 below. The data breakdown includes volumes for EB, WB, NB, and SB directions, with specific counts for left-turn, through, and right-turn movements and pedestrian crossing data.

Table 2. Hourly Traffic Volume and Pedestrian Data.

Eastbound				Westbound			
Left	Thru	Right[1]	Ped[2]	Left	Thru	Right[1]	Ped[2]
288	1380	152	64	176	1612	52	188
Northbound				Southbound			
Left	Thru	Right[1]	Ped[2]	Left	Thru	Right[1]	Ped[2]
488	112	372	40	220	72	400	60

[1] represents right-turn movement counts after subtracting RTORs. [2] represents pedestrian counts crossing in front of traffic.

2.2. Signal Timing

Managing signalized intersections involves determining the number and timing of traffic signal phases to ensure smooth traffic flow and reduce congestion [11]. The selected intersection uses pre-timed signal control which includes an overlap right-turn phase for NB and SB right-turn movements. This overlap phase allows simultaneous right turns while conflicting directions receive red signals, optimizing the flow of right-turning traffic. Signal timing data was sourced from the Miami-Dade County Traffic Signal Documents and captured on 4 October 2021 [12]. Figure 3 shows the overlap right-turn phase condition in the intersection. The signal phases include key parameters such as Maximum Green, Yellow (Y) Change, and Red (R) Clearance times. The specifics of these times have been used to model the current intersection capacity and congestion. During the PM peak period, the intersection has been operated with a cycle length of 190 seconds under Plan 12, specifically designed to accommodate the high traffic volumes observed between 5:15 PM and 5:30 PM. The cycle timings have been highlighted with a red border in Tables 3 and 4 respectively.

Figure 3. Overlap Right-Turn Phase. Source: Google Street View, 2020.

Table 3. Yellow Change & Red Clearance Times.

Phase	Walk Phase			Don't Walk			Min Initial			Veh Ext			Max Limit			Max 2			Y	R
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	-	-
EBL	0	0	0	0	0	0	5	5	5	3	2	1	7	7	5	36	20	36	4.8	2
WBT	5	5	5	20	20	20	18	18	18	2.5	2.5	1	45	45	26	0	60	60	4.8	2
SBT	5	5	5	29	29	29	7	7	7	2.5	5	1	12	12	10	40	25	32	4	3.6
NBT	5	5	5	28	28	28	7	7	7	2.5	2.5	1	10	10	10	31	15	32	4	3.6
WBL	0	0	0	0	0	0	5	5	5	3	2	1	7	7	5	47	20	27	4.8	2
EBT	5	5	5	20	20	20	18	18	18	2.5	2.5	1	45	45	26	0	60	60	4.8	2

Source: Miami-Dade County Traffic Signal Documents, 2025.

Table 4. Maximum Green Time.

Plan	Cycle	EBL	WBT	SBT	NBT	WBL	EBT	Offset
1	140	13	54	23	20	13	54	36
2	160	17	64	27	22	9	72	103
3	180	28	62	31	29	15	75	68
4	190	28	81	31	20	20	89	57
7	160	18	74	24	14	18	74	65
9	160	18	67	31	14	13	72	156
11	170	17	85	24	14	13	89	126
12	190	9	113	24	14	17	105	127
13	160	16	55	29	30	17	54	111
14	140	17	36	28	29	17	36	10
15	120	6	31	26	27	6	31	3
16	120	9	45	19	17	9	45	32
17	120	9	45	19	17	9	45	36
18	130	7	47	24	22	7	47	90
20	150	12	53	28	27	6	59	27
21	160	23	48	30	29	19	52	9
22	130	10	43	25	22	7	46	3
23	120	10	33	25	22	7	36	3

Source: Miami-Dade County Traffic Signal Documents, 2025.

2.3. Considerations

Field survey data included a 3% heavy vehicle percentage for traffic flow and the application of Arrival Type 4 for east-west through movements, with Arrival Type 3 used for other movements. Arrival Type 3 is typically employed when signal coordination is absent, or vehicle arrivals are random due to dispersed platoons. Arrival Type 4 represents moderately dense platoons arriving during the middle of the green interval or dispersed platoons with 40%-80% of the group volume arriving throughout the green. A 25-foot corner radius and 40-foot detector length were used for all approaches. The saturation flow rate is set at 1900 passenger cars per hour per lane, and pre-timed signal control is used. Buses were excluded from the analysis, as bus frequency was approximately one every 1.5 hours. The peak hour factor (PHF) was calculated as per HCM [2] and found to be 1.0. The posted speed limit was 40 mi/h, a minimum green time of 6 seconds was applied to all phases, and the intersection grade was 0%. Table 5 provides an indication of the quality of progression associated with selected platoon ratio values.

Table 5. Relationship Between Arrival and Progression Quality.

Platoon Ratio	Arrival Type	Progression Quality
0.33	1	Very Poor
0.67	2	Unfavorable
1.00	3	Random Arrivals
1.33	4	Favorable
1.67	5	Highly Favorable
2.00	6	Exceptionally Favorable

Source: HCM, 2022 (7th edition).

2.4. Analysis Framework

The operational analysis of the intersection has been conducted using HCS7, following the methodology outlined in the HCM (7th Edition) [13]. Initially, the existing condition of the intersection has been modelled to establish a baseline, providing a comprehensive understanding of its operational performance during peak hour traffic. Following this, two alternatives have been explored to assess their potential impact on intersection efficiency and congestion reduction. These improvements include signal timing optimization, which involve adjusting green signal period and cycle lengths to improve the distribution of green time and minimize delays. Further, phase sequence modifications have been tested to reduce conflict between opposing traffic movements, enhancing safety and traffic flow. However, inclusion of separate elevated pedestrian crossing bridge has been proposed to mitigate pedestrian-related delays and minimize interruptions to vehicular traffic. Each improvement scenario has been rigorously compared to the baseline conditions to quantify the resulting benefits, focusing on key performance indicators such as delay reduction, LOS improvement, and overall enhancement of traffic flow. This data-driven approach has allowed to identify the most effective strategies for mitigating conges gestion and improving intersection operation. The LOS values used in this study have obtained from Exhibit 19-8 of the Highway Capacity Manual (HCM, 7th Edition) [13], as shown in Table 6.

Table 6. LOS Criteria for Motorized Vehicle Mode.

Control Delay	LOS by Volume-to-Capacity Ratio[1]	
(s/veh)	≤ 1	> 1.0
≤ 10	A	F
> 10-20	B	F
> 20-35	C	F
> 35-55	D	F
> 55-80	E	F
> 80	F	F

[1] V/C ratio > 1.0 indicates oversaturated conditions, resulting in LOS F regardless of delay. Source: HCM, 2022 (7th edition).

3. Results

3.1. Baseline Performance

Demand information and signal timing were input into HCS7 to evaluate the existing performance. The baseline analysis highlighted significant operational inefficiencies at the signalized intersection. The Queue Storage Ratio (RQ) exceeded critical thresholds for multiple movements,

with the SB Right Turn exhibiting an RQ of 11.13 and the Northbound Through (NBT) and Northbound Right (NBR) movements having RQ values of 3.56 and 5.94, respectively. These elevated RQ values point to severe queue spillbacks, particularly in the SB and NB directions. The intersection operates at LOS F, with a total intersection delay of 167 seconds per vehicle, demonstrating the magnitude of congestion and delay during peak traffic periods. The NB approach experienced the highest delay (630.7 seconds per vehicle), reinforcing the substantial operational inefficiencies. Figures 4 and 5 illustrate the input and results of the baseline operational performance respectively.

HCS7 Signalized Intersection Results Summary

General Information

				Intersection Information	
Agency				Duration, h	0.250
Analyst		Analysis Date	Apr 8, 2025	Area Type	Other
Jurisdiction		Time Period	5:15 - 5:30	PHF	1.00
Urban Street	SW109th Avenue and S…	Analysis Year	2025	Analysis Period	1> 7:00
Intersection	Four-legged	File Name	Intersection_BaselineOutput.xus		
Project Description					

Demand Information

Approach Movement		EB			WB			NB			SB		
		L	T	R	L	T	R	L	T	R	L	T	R
Demand (v), veh/h		288	1380	152	176	1612	52	488	112	372	220	72	400

Signal Information

Cycle, s	188.8	Reference Phase	2									
Offset, s	0	Reference Point	End	Green	9.0	1.2	105.0	14.0	24.0	0.0		
Uncoordinated	Yes	Simult. Gap E/W	Off	Yellow	4.8	4.8	4.8	4.0	4.0	0.0		
Force Mode	Fixed	Simult. Gap N/S	Off	Red	2.0	2.0	2.0	3.6	3.6	0.0		

Timer Results

	EBL	EBT	WBL	WBT	NBL	NBT	SBL	SBT
Assigned Phase	5	2	1	6		8		4
Case Number	1.1	4.0	2.0	4.0		9.0		9.0
Phase Duration, s	15.8	111.8	23.8	119.8		21.6		31.6
Change Period, ($Y+R_c$), s	6.8	6.8	6.8	6.8		7.6		7.6
Max Allow Headway (MAH), s	3.1	3.0	3.1	3.0		3.3		3.4
Queue Clearance Time (g_s), s	11.0	20.0	11.3	22.8		16.0		26.0
Green Extension Time (g_e), s	0.0	4.1	0.2	4.3		0.0		0.0
Phase Call Probability	1.00	1.00	1.00	1.00		1.00		1.00
Max Out Probability	1.00	0.00	0.04	0.00		1.00		1.00

Movement Group Results

Approach Movement	EB			WB			NB			SB		
	L	T	R	L	T	R	L	T	R	L	T	R
Assigned Movement	5	2	12	1	6	16	3	8	18	7	4	14
Adjusted Flow Rate (v), veh/h	288	1173	359	176	1121	543	195	405	372	220	72	400
Adjusted Saturation Flow Rate (s), veh/h/ln	1767	1856	1696	1716	1856	1797	1767	1792	1318	1767	1856	1350
Queue Service Time (g_s), s	9.0	14.3	18.0	9.3	19.3	20.8	14.0	14.0	14.0	23.4	6.7	24.0
Cycle Queue Clearance Time (g_c), s	9.0	14.3	18.0	9.3	19.3	20.8	14.0	14.0	14.0	23.4	6.7	24.0
Green Ratio (g/C)	0.60	0.56	0.56	0.09	0.60	0.60	0.07	0.07	0.16	0.13	0.13	0.17
Capacity (c), veh/h	264	3096	943	309	2221	1075	131	133	239	225	236	247
Volume-to-Capacity Ratio (X)	1.091	0.379	0.380	0.570	0.505	0.505	1.490	3.047	1.554	0.979	0.305	1.622
Back of Queue (Q), ft/ln (95 th percentile)	547.9	231.5	279.1	202	261.3	283.2	641	1621.4	1127.8	518.2	156.4	1268.9
Back of Queue (Q), veh/ln (95 th percentile)	21.4	9.0	11.2	7.9	10.2	11.3	25.0	63.3	44.1	20.2	6.1	49.6
Queue Storage Ratio (RQ) (95 th percentile)	1.00	0.21	0.25	0.76	0.23	0.26	1.41	3.56	5.94	2.13	0.42	11.13
Uniform Delay (d_1), s/veh	35.3	12.7	17.2	82.4	9.6	10.7	87.4	87.4	79.6	82.2	74.8	78.4
Incremental Delay (d_2), s/veh	81.9	0.4	1.2	7.4	0.8	1.7	256.3	940.9	269.0	55.0	3.3	298.0
Initial Queue Delay (d_3), s/veh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Control Delay (d), s/veh	117.1	13.0	18.3	89.8	10.4	12.4	343.7	1028.3	348.6	137.1	78.1	376.4
Level of Service (LOS)	F	B	B	F	B	B	F	F	F	F	E	F
Approach Delay, s/veh / LOS	30.5		C	18.6		B	630.7		F	269.3		F
Intersection Delay, s/veh / LOS					167.0						F	

Multimodal Results

	EB		WB		NB		SB	
Pedestrian LOS Score / LOS	2.27	B	2.10	B	2.89	C	2.75	C
Bicycle LOS Score / LOS	1.24	A	1.50	A	2.09	B	1.63	B

Figure 4. Data Input and Configuration in HCS7 Software for Baseline Operational Performance Evaluation.

3.2. Scenario 1: Signal Timing Optimization

To improve the baseline operational performance of the intersection, signal timing was optimized by adjusting green time allocation, cycle length, and phase sequencing. These changes led to a significant reduction in RQ values across most movements. The NBT RQ improved from 3.56 to 1.31, a 63.5% reduction. Similarly, the SBR RQ decreased from 11.13 to 5.44, a 51.12% reduction. Consequently, the overall delay decreased to 81.8 seconds per vehicle, a 51.02% improvement. Although the overall LOS remained F, individual approach delays improved significantly. NB and SB delays reduced to 60.1 and 74 seconds per vehicle, respectively, highlighting the operational improvement from the signal timing changes as shown in Figures A1 and A2. Table 7 shows the comparison between both scenario and Figure 6 illustrates the changes in percentage of Maximum green time.
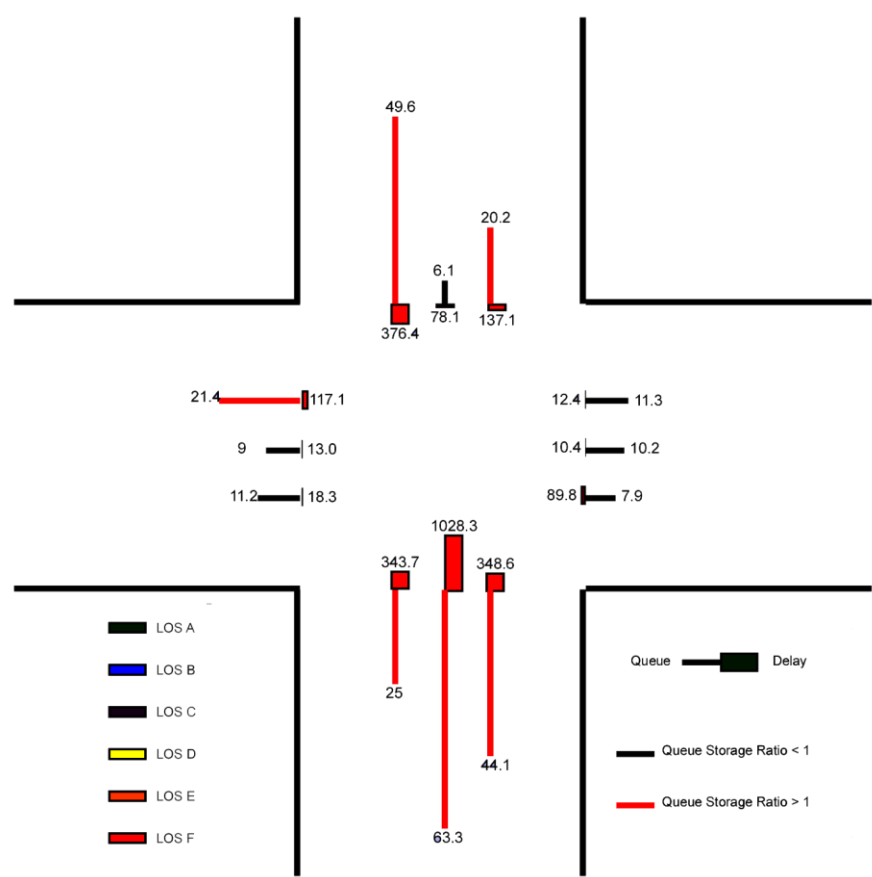
Figure 5. Results of the Intersection from Baseline Scenario.

Table 7. Signal Timing Parameters: Baseline vs. Scenario 1.

Timing	Assigned Phase	Eastbound			Westbound			Northbound			Southbound		
		Left	Thru	Right	Left	Thru	Right	Left	Thru	Right	Left	Thru	Right
		5	2	-	1	6	-	-	8	-	-	4	-
Baseline Scenario	Maximum Green	9	105	-	17	113	-	-	14	-	-	24	-
	Yellow Change	4.8	4.8	-	4.8	4.8	-	-	4	-	-	4	-
	Red Clearance	2	2	-	2	2	-	-	3.6	-	-	3.6	-
After Improvement	Maximum Green	20	30	-	9	40	-	-	40	-	-	25	-
	Yellow Change	4.8	4.8	-	4.8	4.8	-	-	4	-	-	4	-
	Red Clearance	2	2	-	2	2	-	-	2	-	-	2	-

Source: Miami-Dade County Traffic Signal Documents, 2025.
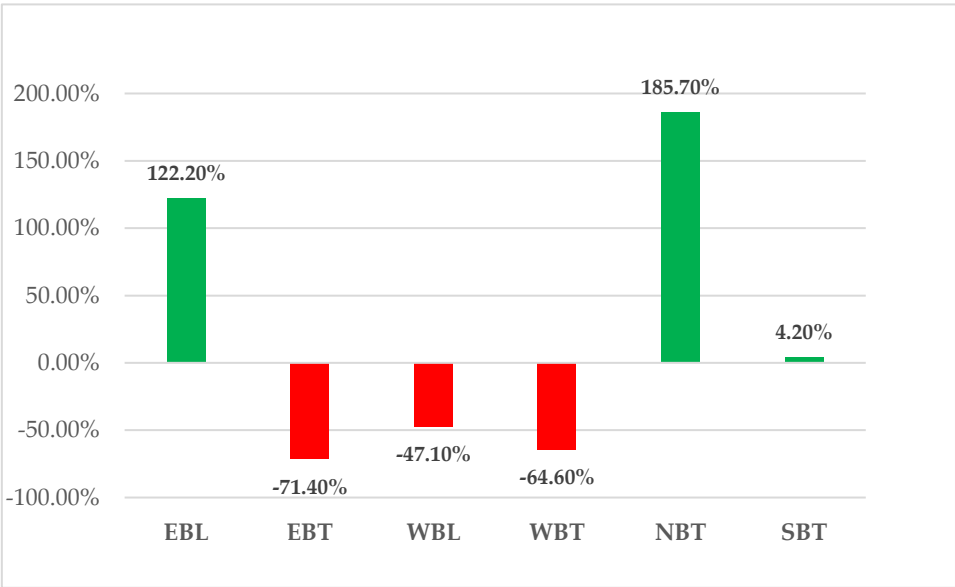
Figure 6. Percentage change in maximum green time by movement between the baseline and optimized signal timing scenarios.

As shown in Figure 6, green time was redistributed by substantially cutting allocations for the east–west through phases—roughly 71% for EBT and 65% for WBT. The time saved from these movements was reassigned to approaches under heavier demand, most notably EBL, which more than doubled its allocation, and NBT, which received nearly three times its original share. By shifting capacity to the most constrained approaches, the revised timing plan helped relieve congestion and played a key role in improving overall intersection performance, although the overall LOS remained at F.

3.3. Scenario 2: Signal Timing with Elimination of Pedestrian Signal

The second scenario proposed eliminating pedestrian signal phases by constructing a grade-separated pedestrian bridge, combined with signal timing changes. The SBR RQ decreased to 5.12, representing a 54% reduction from the baseline. Overall delay dropped to 78.5 seconds per vehicle, a 52.99% improvement over the baseline. Consequently, the LOS improved from F to E, reflecting a significant increase in operational efficiency. Furthermore, approach delays continued to decline, reaching 59.2 seconds per vehicle (NB) and 68.6 seconds per vehicle (SB). Eliminating pedestrian signal delays combined with optimized signal timing had a positive, cumulative effect on traffic flow and overall performance of the intersection. The changes in parameters regarding signal timing and the outputs have been demonstrated in Figures A3 and A4.

3.4. Comprehensice Performance Comparison

To provide a comprehensive comparison of operational outcomes, Figure 7 emphasized four key performance metrics across the baseline, Scenario 1, and Scenario 2. Figure 7a showed clear reductions in Queue Storage Ratio (RQ) for all movements, with the most notable improvements in the NBT and SBT movements, each reducing more than half of their baseline values. Figure 7b illustrated consistent LOS upgrades from F to D/E
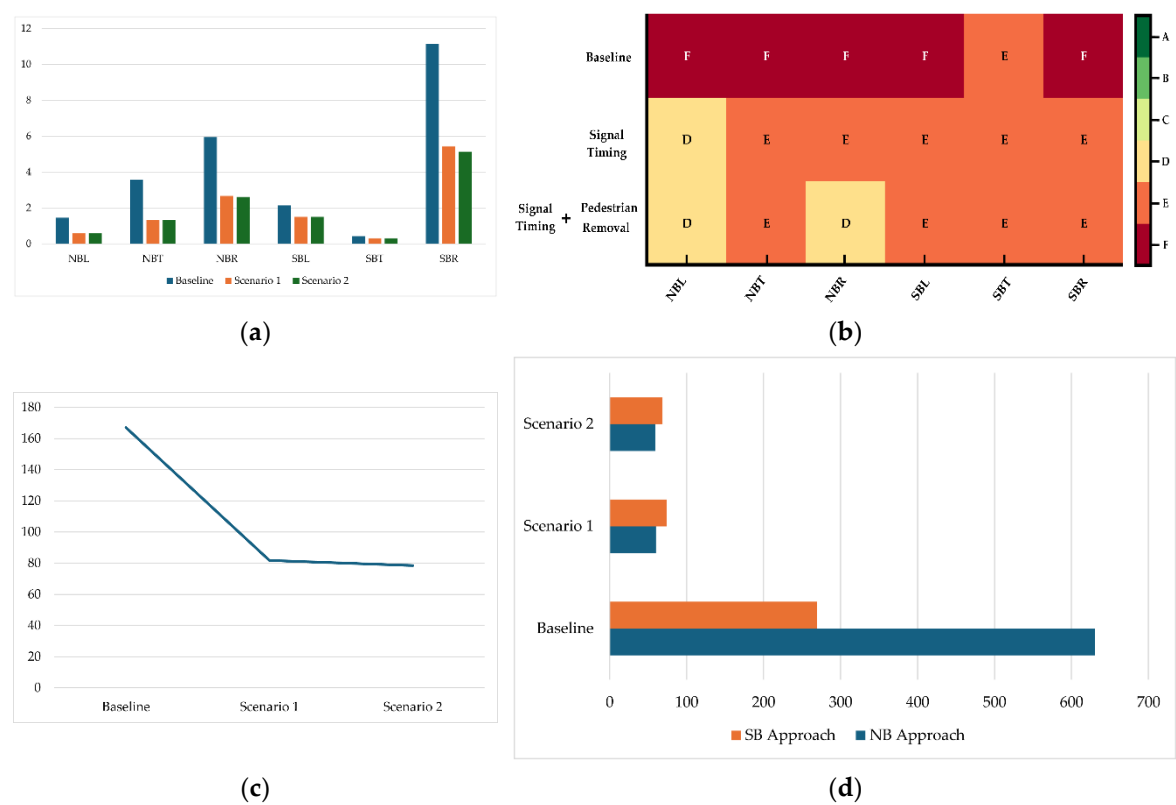
Figure 7. Comparative performance of the intersection under baseline and improvement scenarios: (a) Queue Storage Ratio (RQ) by movement, (b) Level of Service (LOS) changes, (c) Intersection delay by scenario, and (d) Approach delay reduction.

in most approaches, with Scenario 2 achieving significant improvements. Figure 7c highlighted the downward trend in intersection delay, dropping by over 50% from the baseline in Scenario 1 and slightly further in Scenario 2. Furthermore, Figure 7d confirms substantial approach delay reductions, exceeding 90% for the Northbound approach and around 75% for the Southbound approach. Collectively, these results indicated that while Scenario 1 delivered overall operational efficiency, Scenario 2 provided additional performance benefits alongside improved safety eliminating the probability of pedestrian–vehicle conflicts.

4. Discussion

Conventional four-legged intersections, while common, are often inefficient due to heavy traffic movements and highly susceptible to congestion issues [14]. This study examined the operational performance of the conventional four-legged signalized intersection focusing on LOS and RQ improvements using HCS7, proposing two scenarios to increase efficiency. The best alternative, which incorporated signal time optimization and a grade-separated pedestrian bridge, showed a 53% reduction in delays, resulting in LOS E from F. While HCS7 provides a standardized assessment, tools like Vissim could capture more detailed lane-level interactions. Using the Surrogate Safety Assessment Model (SSAM), Mohamed et al. [15] evaluated a Displaced Left-Turn (DLT) intersection using Vissim reducing average delay over 48% with corresponding improvements in capacity and fuel consumption under both balanced and unbalanced traffic conditions. In comparison, without geometric reconfiguration, improvement scenario 1 resulted in a 51.02% reduction in average delays with substantial improvement in RQ – for instance, NBT movements improve from 3.56 to 1.31. Although the delay and queue length decreased, the LOS remained F in the HCS7 framework. These improvements have wider implications for urban mobility: reduced delays can lead to less vehicle idle time, lower fuel use, and decreased greenhouse gas emissions, as supported by the findings in [14,16]. However, in case of improvement scenario 2 the study has eliminated pedestrian signal phase

by proposing a grade-separated crossing. As a result, the average delay dropped further to 78.5 s/veh, and the LOS improved from F to E. Arshi et al. [16], using a custom HCM-based model, assessed the performance of two-way stop control (TWSC), roundabouts and signalized intersections. They suggested that eliminating pedestrian delays yields significant operational gains across all control types as the intersections become increasingly inefficient as pedestrian demand rises. Similarly, implementing a grade-separated crossing in this study significantly improved performance. In addition, [17] suggested to follow the designs that mitigate crash risk for vulnerable road users, which recommended to remove pedestrian-vehicle conflict points according to their guidelines. The guidelines further recognized grade-separated crossings such as pedestrian overpass as effective countermeasures in high volume traffic areas, offering greater safety and maintainability. Similar safety measures were noted by Turner et al. [18], where grade separation at high volume intersections significantly reduced pedestrian crash exposure and enhanced flow efficiency. In both improvement scenarios of this research, signal optimization has been conducted. HCS7 based analysis achieved RQ reduction over 50% and improved LOS without any geometric change of intersection, for example, SBR RQ dropped from 11.13 in the baseline to 5.12 which demonstrates significant capacity gains with its deterministic framework. Bai et al. [19], using a custom framework signal optimization modeling for Signalized Turbo Roundabouts (STRAB). Results showed that STRABs outperform the conventional signalized intersections under high right-turn demand and saturated flow. Allowing detailed changes and performing twice-stop-right-turn (TSRT) control, it has minimized internal weaving. Thus, their customized framework and modeling approach have allowed adaptive phasing, complex geometry, and spiral lane transitions, whereas in HCS7, these features are not supported.

5. Limitations and Scope

This analysis was conducted using the HCS7 framework, which follows the deterministic methodologies of the Highway Capacity Manual. On the positive side, several studies have shown that HCS can produce delay estimates with very low average error margins (≈1.9%) and high coefficients of determination ($R^2 ≈ 0.99$), making it a reliable tool for preliminary planning and policy assessments [20]. Such consistency emphasizes its value as a benchmark framework in capacity and delay evaluation. However, field studies have shown that HCS often overestimates control delay, especially at higher congestion levels, where its interpretation differs from observed conditions [21]. By contrast, tools like SIDRA and Synchro have demonstrated closer agreement with field conditions under certain ranges, though they may introduce larger deviations when compared directly with HCM benchmarks [20,21]. Moreover, microsimulation-based models such as Vissim reveal additional weaknesses in deterministic approaches like HCS, as they cannot fully account for dynamic driver behavior, stochastic arrival patterns, queue spillback, or midblock interactions. Studies comparing HCS with Vissim reported deviations of up to 20–35% in critical indicators such as delay and flow density in some cases [22], suggesting that small changes in traffic demand may produce disproportionately higher delays in real-world conditions than HCS predicts. Although deterministic approach of HCS limits its ability to represent the variability and complexity of observed traffic conditions. More detailed design and safety assessment therefore require support from calibrated models. Tools like Vissim, SIDRA, and other custom models provide dynamic and stochastic capabilities, but HCS7 remains a reliable and standardized option for early diagnostics, and policy decisions, particularly in settings with limited data or simulation expertise. Future research should focus on dynamic simulation tools which considers vehicle–pedestrian interactions, lane use patterns, and adaptive phasing. Applying models such as SSAM would also enable a quantitative assessment of conflict frequency and severity, offering a stronger basis for safety evaluation. Incorporating environmental impact assessment and cost–benefit analysis of alternative scenarios derived from the software outcomes would provide stronger evidence to support decision-making and policy development.

6. Conclusions

This study evaluated the performance of one of the congested four-legged signalized intersections of Miami comparing baseline conditions and two improvement scenarios using HCS7. In Scenario 1, signal optimization alone reduced delays and RQ values, though the overall LOS remained at F. In contrast, Scenario 2, which combined optimized timing with the elimination of pedestrian phases through a grade-separated crossing, offered the best alternative, cutting delays by more than 50% and upgrading the overall LOS from F to E. Improving efficiency with both alternatives, proposal of pedestrian bridge further enhanced safety by eliminating vehicle-pedestrian conflicts offering broader societal benefits through potential reductions in fuel use, emissions, and crash risks. Consequently, while HCS7 offered a practical and standardized framework for assessing congested intersections, its deterministic approach limits how well it reflects the dynamic nature of real traffic, pointing to the need for future studies that employ advanced microsimulation tools and integrated safety evaluations. In conclusion, the results indicated targeted operational strategies, specifically signal optimization combined with pedestrian grade separation which represented a practical approach for improving performance at congested intersections where geometric expansion was not a viable option.

Appendix A

Figure A1. Data Input and Configuration in HCS7 Software for Improvement Scenario 1.
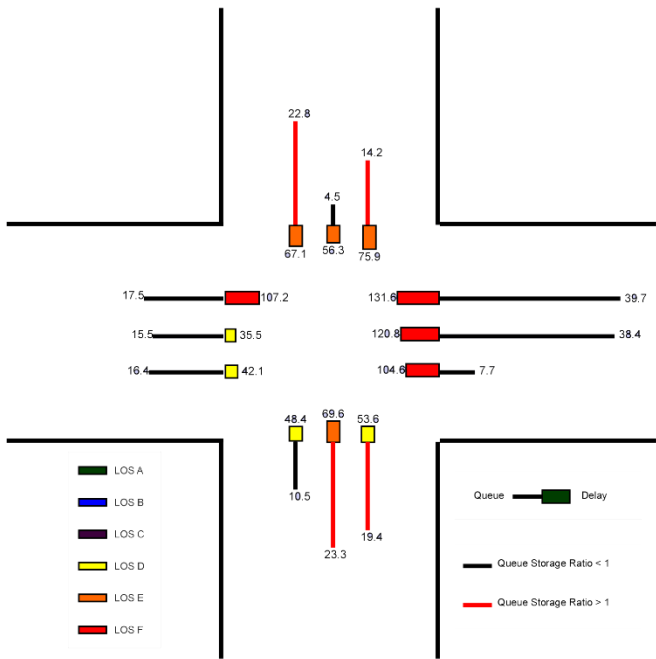

Figure A2. Results of the Intersection from Improvement Scenario 1.

HCS7 Signalized Intersection Results Summary

General Information		Intersection Information	
Agency		Duration, h	0.250
Analyst	Analysis Date	Apr 8, 2025	Area Type	Other
Jurisdiction	Time Period	5:15 - 5:30	PHF	1.00
Urban Street	SW109th Avenue and S…	Analysis Year	2025	Analysis Period	1> 7:00
Intersection	Four-legged	File Name	Intersection_ImprovementScenario02.xus	
Project Description			

Demand Information		EB			WB			NB			SB		
Approach Movement		L	T	R	L	T	R	L	T	R	L	T	R
Demand (v), veh/h		288	1380	152	176	1612	52	488	112	372	220	72	400

Signal Information										
Cycle, s	150.6	Reference Phase	2							
Offset, s	0	Reference Point	End	Green	9.0	4.2	40.0	40.0	25.0	0.0
Uncoordinated	Yes	Simult. Gap E/W	Off	Yellow	4.8	4.8	4.8	4.0	4.0	0.0
Force Mode	Fixed	Simult. Gap N/S	Off	Red	2.0	2.0	2.0	2.0	2.0	0.0

Timer Results	EBL	EBT	WBL	WBT	NBL	NBT	SBL	SBT
Assigned Phase	5	2	1	6		8		4
Case Number	1.1	4.0	2.0	4.0		9.0		9.0
Phase Duration, s	26.8	57.8	15.8	46.8		46.0		31.0
Change Period, ($Y+R_c$), s	6.8	6.8	6.8	6.8		6.0		6.0
Max Allow Headway (MAH), s	3.1	3.0	3.1	3.0		3.1		3.2
Queue Clearance Time (g_s), s	22.0	27.2	9.7	42.0		34.3		27.0
Green Extension Time (g_e), s	0.0	1.4	0.0	0.0		1.3		0.0
Phase Call Probability	1.00	1.00	1.00	1.00		1.00		1.00
Max Out Probability	1.00	1.00	1.00	1.00		0.40		1.00

Movement Group Results		EB			WB			NB			SB		
Approach Movement		L	T	R	L	T	R	L	T	R	L	T	R
Assigned Movement		5	2	12	1	6	16	3	8	18	7	4	14
Adjusted Flow Rate (v), veh/h		288	1169	363	176	1115	549	195	405	372	220	72	400
Adjusted Saturation Flow Rate (s), veh/h/ln		1767	1856	1726	1716	1856	1824	1767	1792	1572	1767	1856	1572
Queue Service Time (g_s), s		20.0	24.1	25.2	7.7	40.0	40.0	13.7	32.3	31.5	17.9	5.1	25.0
Cycle Queue Clearance Time (g_c), s		20.0	24.1	25.2	7.7	40.0	40.0	13.7	32.3	31.5	17.9	5.1	25.0
Green Ratio (g/C)		0.41	0.34	0.34	0.06	0.27	0.27	0.27	0.27	0.33	0.17	0.17	0.30
Capacity (c), veh/h		282	1885	584	205	986	485	469	476	512	293	308	470
Volume-to-Capacity Ratio (X)		1.019	0.620	0.622	0.858	1.132	1.132	0.416	0.851	0.727	0.750	0.234	0.851
Back of Queue (Q), ft/ln (95 th percentile)		448.2	397.6	409.9	197.9	982.3	992.1	268.7	596.2	495.6	364.1	115.8	584.2
Back of Queue (Q), veh/ln (95 th percentile)		17.5	15.5	16.4	7.7	38.4	39.7	10.5	23.3	19.4	14.2	4.5	22.8
Queue Storage Ratio (RQ) (95 th percentile)		0.81	0.35	0.37	0.74	0.88	0.91	0.59	1.31	2.61	1.50	0.31	5.12
Uniform Delay (d_1), s/veh		48.6	33.9	37.2	70.2	48.6	49.3	45.7	52.5	44.9	59.8	54.5	49.7
Incremental Delay (d_2), s/veh		58.6	1.5	4.9	34.5	72.1	82.4	2.7	17.2	8.7	16.1	1.8	17.4
Initial Queue Delay (d_3), s/veh		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Control Delay (d), s/veh		107.2	35.5	42.1	104.6	120.8	131.6	48.4	69.6	53.6	75.9	56.3	67.1
Level of Service (LOS)		F	D	D	F	F	F	D	E	D	E	E	E
Approach Delay, s/veh / LOS		48.1		D	122.5		F	59.2		E	68.8		E
Intersection Delay, s/veh / LOS			78.5						E				

Multimodal Results		EB		WB		NB		SB	
Pedestrian LOS Score / LOS		2.30	B	2.14	B	2.88	C	2.74	C
Bicycle LOS Score / LOS		1.24	A	1.50	A	2.09	B	1.63	B

Figure A3. Data Input and Configuration in HCS7 Software for Improvement Scenario 2.
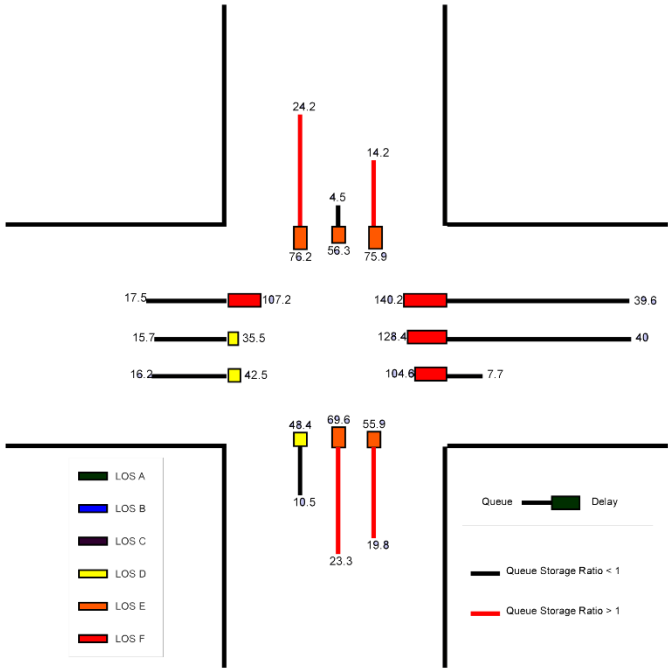

Figure A4. Results of the Intersection from Improvement Scenario 2.

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