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Assessing the Environmental Impact of Traffic Signal Optimization: CO_2 Emission Reduction Potential at a Signalized Intersection in Tobruk, Libya

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تقييم الأثر البيئي لتحسين إشارات المرور: إمكانية خفض انبعاثات ثاني أكسيد الكربون عند تقاطع مُجهز بإشارات مرور في طبرق، ليبيا

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Abstract:

Urban intersections in developing cities contribute significantly to vehicular CO_2 emissions due to inefficient traffic signal timing. This study investigates the environmental benefits of optimizing traffic signal coordination at a congested intersection in Tobruk, Libya, using SIDRA Intersection 5 software. Field data were collected during morning (7:30–8:30 AM) and evening (1:30–2:30 PM) peak hours via video recording and manual counting. Three signal timing scenarios were evaluated: (1) existing fixed-time operation, (2) coordinated fixed-time, and (3) coordinated actuated control. Environmental performance was assessed based on estimated CO_2 emissions, alongside operational indicators such as average delay, travel speed, and fuel consumption. Results show that the coordinated actuated scenario reduces CO_2 emissions by approximately 27–34% compared to the existing condition, while also improving average travel speed by 25% and reducing delay by 30%. The study concludes that signal coordination offers a low-cost, high-impact strategy for mitigating environmental externalities in mid-sized cities. Recommendations include adopting actuated control systems and integrating environmental metrics into traffic management policies in Libya.

Keywords: Traffic signal optimization; CO_2 emissions; Roundabout; SIDRA Intersection; Tobruk; Environmental impact.

الملخص

تُساهم التقاطعات الحضرية في المدن النامية بشكل كبير في انبعاثات ثاني أكسيد الكربون الناتجة عن المركبات، وذلك بسبب عدم كفاءة توقيت إشارات المرور. تبحث هذه الدراسة في الفوائد البيئية لتحسين تنسيق إشارات المرور عند تقاطع مزدحم في طبرق، ليبيا، باستخدام برنامج SIDRA Intersection 5. جُمعت البيانات الميدانية خلال ساعات الذروة الصباحية (7:30-8:30 صباحًا) والمسائية (1:30-2:30 ظهرًا) عبر تسجيل الفيديو والعد اليدوي. جرى تقييم ثلاثة سيناريوهات لتوقيت الإشارات: (1) التشغيل الحالي ذو التوقيت الثابت، (2) التوقيت الثابت المنسق، و(3) التحكم المنسق المُفعّل. قُيّم الأداء البيئي بناءً على انبعاثات ثاني أكسيد الكربون المُقدَّرة، إلى جانب مؤشرات تشغيلية مثل متوسط التأخير، وسرعة السير، واستهلاك الوقود. تُظهر النتائج أن سيناريو التحكم المنسق المُفعّل يُقلل انبعاثات ثاني أكسيد الكربون بنسبة تتراوح بين 27% و34% تقريبًا مقارنةً بالوضع الحالي، مع تحسين متوسط سرعة السير بنسبة 25% وتقليل التأخير بنسبة 30%.

تخلص الدراسة إلى أن تنسيق الإشارات المرورية يمثل استراتيجية منخفضة التكلفة وعالية التأثير للتخفيف من الآثار البيئية السلبية في المدن متوسطة الحجم. وتشمل التوصيات اعتماد أنظمة تحكم آلية ودمج المقاييس البيئية في سياسات إدارة المرور في ليبيا.

الكلمات المفتاحية: تحسين إشارات المرور؛ انبعاثات ثاني أكسيد الكربون؛ الدوار؛ تقاطع سدرة؛ طبرق؛ الأثر البيئي.

Introduction

Urban transportation systems in developing cities face mounting challenges from rapid motorization, inadequate public transport, and outdated traffic control infrastructure. Signalized intersections contribute disproportionately to vehicular emissions due to frequent stops, prolonged idling, and inefficient signal timing (Albalate & Fageda, 2019; Falcocchio & Levinson, 2015). While the operational impacts of traffic congestion—such as delay and travel time—have been extensively studied, the environmental externalities, particularly CO_2 emissions, remain underexplored in many mid-sized cities of North Africa and the Middle East.

The city of Tobruk, Libya, exemplifies these challenges. As a border hub with significant port activities and cross-border freight movement, Tobruk experiences severe peak-hour congestion at key intersections, notably the Alhuria intersection. This junction serves as a critical link connecting commercial districts, government offices, and residential neighborhoods. Despite persistent commuter complaints regarding delays and environmental degradation, no systematic evaluation of signal optimization as an emissions-reduction strategy has been undertaken. Existing traffic management practices rely on fixed-time signals, which fail to adapt to fluctuating demand, resulting in excessive fuel consumption and elevated CO_2 output. The selected location is Alhuria intersection and is illustrated in Figure 1.1 as follows.

Figure 1: Location Map of Tobruk City and Alhuria Intersection, Libya, **Source**: (Google Earth).

This study addresses this gap by evaluating the environmental co-benefits of traffic signal coordination at the Alhuria intersection using SIDRA Intersection 5 software. Three operational scenarios—existing fixed-time, coordinated fixed-time, and coordinated actuated control—are modeled to assess their impact on CO_2 emissions, alongside operational metrics such as delay and travel speed. The findings aim to provide evidence-based recommendations for integrating environmental performance criteria into traffic management policies in Tobruk and similar developing urban contexts.

2. Literature Review

Urban intersections represent critical nodes within transportation networks, yet they are also significant sources of vehicular emissions due to frequent deceleration, idling, and acceleration cycles (Albalate & Fageda, 2019; Falcocchio & Levinson, 2015). While extensive research has addressed operational performance measures such as delay, queue length, and level of service (LOS), the environmental dimension—particularly CO_2 emissions—has received comparatively less attention, especially in developing urban contexts (Mfinanga, 2014; Yao et al., 2018).

This review synthesizes existing knowledge on three interconnected themes: (1) traffic congestion and its environmental externalities at signalized intersections, (2) performance measures relevant to emissions assessment, and (3) the application of SIDRA Intersection software for environmental evaluation. The review concludes by identifying a research gap regarding the quantification of emission-reduction potential through signal coordination in North African cities, which this study aims to address.

2.1 Traffic Congestion and Environmental Impacts at Intersections

Traffic congestion occurs when traffic demand exceeds roadway capacity, resulting in extended vehicle queues, increased travel times, and elevated fuel consumption (Adebambo & Adebayo, 2009; Koźlak & Wach, 2018). At signalized intersections, congestion is particularly acute due to the cyclical interruption of traffic flow. Vehicles experience repeated stop-start cycles, which significantly increase engine load and, consequently, CO_2 emissions per kilometer traveled (He et al., 2016).

Several studies have established a direct relationship between intersection delay and environmental degradation. Akçelik (2006) demonstrated that fuel consumption increases exponentially with the number of vehicles stops, with each stop contributing approximately 0.5–1.0 liters of additional fuel per 100 kilometers. Similarly, Bivina et al. (2016) found that reducing average delay by 10 seconds per vehicle at a signalized intersection could lower CO_2 emissions by 8–12% during peak hours.

Signal coordination has been identified as a cost-effective strategy to mitigate these environmental impacts. By synchronizing green phases along arterial routes, coordinated signal systems reduce the frequency of stops and improve overall traffic progression (Oskarbski et al., 2016). Studies from developed countries report emission reductions of 15–30% following signal retiming projects (Koonce, 2008). However, limited empirical evidence exists for Libyan or North African contexts, where traffic management practices often rely on outdated fixed-time signals without environmental performance metrics.

2.2 Performance Measures for Environmental Assessment

The primary operational measures used to evaluate intersection performance are delay, queue length, and level of service (LOS), as defined by the Highway Capacity Manual (HCM, 2000). However, for environmental assessment, additional metrics are required:

Delay: Control delay represents the total time lost due to signal control, including deceleration, queuing, and acceleration phases (Darma et al., 2005). Longer delays correlate directly with higher fuel consumption and emissions. The HCM classifies LOS from A (free flow, 0–10 sec/veh delay) to F (jammed, >80 sec/veh delay), with environmental impacts worsening significantly at LOS D and below.

Speed and Travel Time: Average travel speed is inversely related to emission rates. Vehicles operating at speeds below 30 km/h or above 80 km/h exhibit higher CO_2 output per kilometer (Akçelik, 2005a). Signal coordination aims to maintain speeds within the optimal range of 40–60 km/h.

Fuel Consumption and CO_2 Emissions: Fuel consumption models, such as those embedded in SIDRA, estimate emissions based on vehicle-specific power (VSP), idle time, and acceleration/deceleration events (Akçelik, 2006). SIDRA employs a drive-cycle model that quantifies CO_2 emissions in kilograms per hour, enabling direct comparison of signal timing scenarios (Said, 2016).

2.3 SIDRA Intersection Software for Environmental Analysis

SIDRA (Signalized Intersection Design and Research Aid) is a widely used analytical tool for capacity, timing, and performance analysis of intersections (Muhammet Mevlüt Akmaz & Osman Nuri Çelik, 2016). Developed by the Australian Road Research Board, SIDRA offers several features relevant to environmental assessment:

- **Lane-by-lane modeling:** Enables detailed analysis of individual lane performance, including flow rates, queue lengths, and delay contributions (Albrka Ali et al., 2018).
- **Drive-cycle model:** Estimates fuel consumption, operating costs, and CO_2 emissions based on vehicle acceleration, deceleration, and idling profiles (Said, 2016).
- **Scenario comparison:** Allows users to evaluate multiple signal timing plans and coordination strategies, facilitating identification of environmentally optimal solutions.

Previous studies have validated SIDRA's emission estimates against field measurements. Tianzi et al. (2013) compared VISSIM and SIDRA at a signalized intersection in China, finding that SIDRA provided conservative but reliable emission estimates with less calibration effort. Similarly, Ismael Albrka et al. (2014) used SIDRA to evaluate fuel consumption reductions under coordinated signal timing in Malaysia, reporting savings of 18–25%.

Despite these applications, limited research has employed SIDRA to assess the environmental co-benefits of signal coordination in North African cities, where traffic conditions, driver behavior, and vehicle fleet composition differ from developed contexts. This study addresses this gap by applying SIDRA to evaluate CO_2 emission reduction potential at a representative intersection in Tobruk, Libya.

2.4 Summary and Research Gap

The literature confirms that signalized intersections are significant contributors to urban CO_2 emissions, and that signal coordination offers a low-cost strategy for emission reduction. While SIDRA Intersection software provides robust tools for estimating fuel consumption and emissions, its application in Libyan urban contexts remains unexplored. Furthermore, few studies have quantified the specific emission reductions achievable through coordinated versus fixed-time signal operation in mid-sized developing cities.

This study aims to fill this gap by modeling three signal scenarios—existing fixed-time, coordinated fixed-time, and coordinated actuated control—and comparing their CO_2 emission outcomes. The findings will provide evidence-based recommendations for integrating environmental performance criteria into traffic management policies in Tobruk and similar urban contexts.

3.Methodology

3.1 Study Area Description

This study was conducted at the Alhuria intersection in Tobruk, Libya, a critical four-leg signalized junction connecting commercial districts, government offices, and residential neighborhoods. The intersection experiences severe peak-hour congestion due to high traffic volumes from commuting, educational trips, and cross-border freight movement. Its central location and operational significance make it an ideal case for evaluating the environmental co-benefits of signal coordination strategies. Figure 3.1 illustrates the intersection location.

3.2 Data Collection

Traffic data were collected during representative peak periods morning (7:30–8:30 AM) and evening (1:30–2:30 PM)—on a neutral weekday in February 2020, avoiding holidays or adverse weather conditions. Vehicle movements were recorded using a high-definition video camera mounted on a tripod, supplemented by manual counts to ensure accuracy and consistency. Data were classified into three vehicle categories commonly found in Libya: passenger cars, buses, and heavy-duty vehicles. Volumetric counts were aggregated at 15-minute intervals and converted to Passenger Car Units (PCU) using standard equivalency factors (Cars: 1.0, Buses: 2.0, Heavy Vehicles: 2.2) to standardize flow rates across lane groups. Validation was achieved through repeated review of video recordings to minimize counting errors. The intersection contains four legs and the process of collecting data for unit time for volumes is 60 minutes and the peak flow period is 15 minutes as shown in the Figure 1.

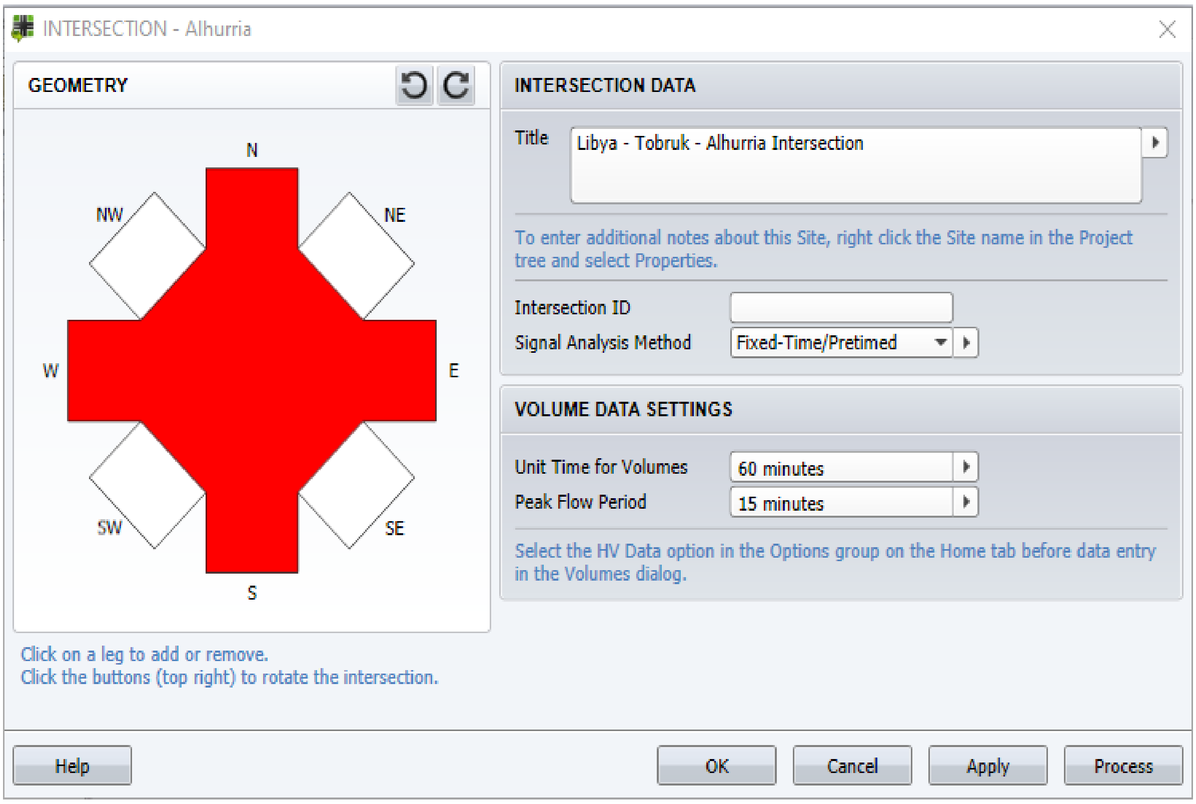


Figure 1: SIDRA Intersection 5 – Site Definition and Approach Setup

3.3 Simulation Scenarios

Three operational scenarios were modeled using SIDRA Intersection 5 software:

Table 1: Three operational scenarios

Scenario	Description
S1: Existing Fixed-Time	Current signal timing plan (baseline)
S2: Coordinated Fixed-Time	Optimized fixed-time plan with coordinated green phases along the major arterial
S3: Coordinated Actuated	Coordinated plan with actuated control responding to real-time demand

These scenarios were selected to compare the environmental performance of conventional versus optimized signal operations.

3.4 SIDRA Model Setup and Calibration

SIDRA Intersection 5 was selected for its lane-by-lane analytical capability and integrated drive-cycle model for estimating fuel consumption and emissionsas shown in Figure 3.2: SIDRA Intersection 5 – Geometric Data Input (Lane Configuration). Model inputs included:

- **Geometric data:** Lane configurations, widths, and lengths for all four approaches.
- **Traffic volume data:** 15-minute flow rates converted to PCU for each movement.
- **Signal timing:** Existing phase plans (four phases: A, B, C, D) with green, yellow, and red intervals.
- **Environmental parameters:** Default SIDRA emission factors calibrated to local vehicle fleet characteristics where possible.

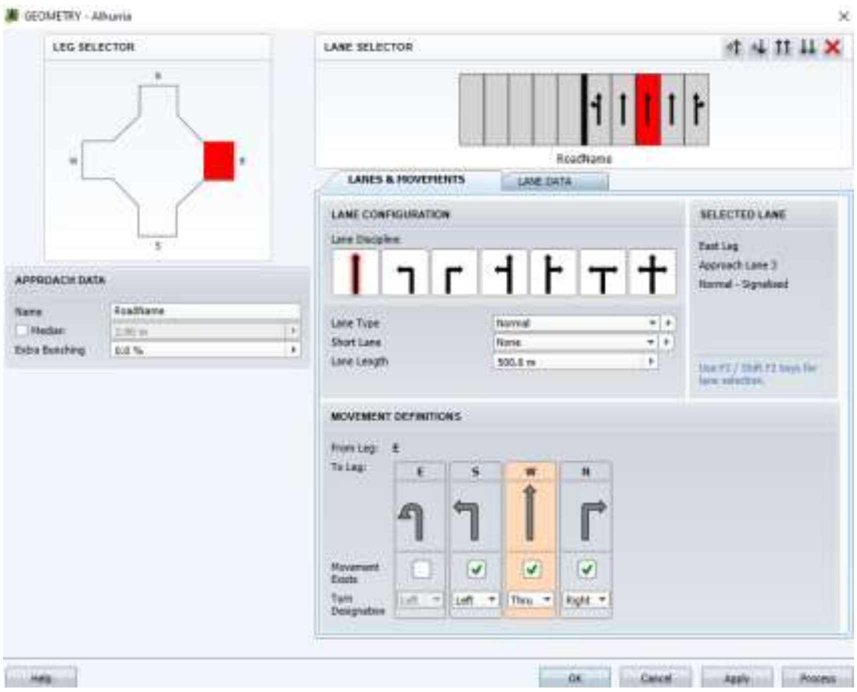


Figure 2: SIDRA Intersection 5 – Geometric Data Input (Lane Configuration)

The model was calibrated against field-observed delays and queue lengths to ensure representative baseline performance. Calibration involved iterative adjustments to saturation flow rates and lost times until simulated outputs matched observed values within acceptable tolerances.

3.5 Performance Evaluation Metrics

Performance was assessed using both operational and environmental metrics:

Table 2: Performance Evaluation Metrics

Metric	Description	Unit
Average Delay	Control delay per vehicle	Seconds/vehicle
Travel Speed	Average speed through the intersection	km/h
CO_2 Emissions	Estimated carbon dioxide output	kg/h
Fuel Consumption	Estimated fuel usage	L/h
Level of Service (LOS)	HCM-based LOS (A–F)	–

CO_2 emissions were estimated using SIDRA's drive-cycle model, which calculates emissions based on vehicle-specific power, idle time, and acceleration/deceleration profiles. Comparative analysis of the three scenarios identified the optimal strategy to minimize environmental impact while maintaining operational efficiency.

4. Results and Discussion

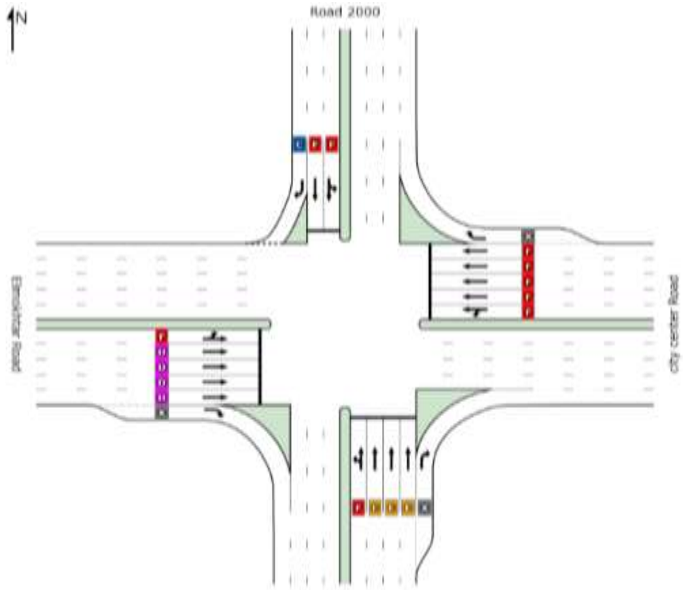
4.1 Baseline Performance (Existing Fixed-Time Signals)

The existing signalized intersection operates with fixed-time phasing across four approaches. Baseline performance metrics derived from SIDRA Intersection 5 simulations are summarized in Table 3.

Table 3: Baseline Performance Summary at Alhuria Intersection (Morning Peak)

Metric	Value
Average Delay	182.2 sec/veh
Level of Service (LOS)	F
Fuel Consumption	1232.1 L/h
CO_2 Emissions	3080.2 kg/h
Degree of Saturation	2.26 v/c ratio

All four approaches exhibited LOS F, indicating severe congestion with excessive delays and elevated emissions. The morning peak recorded significantly higher traffic volumes (6912 vehicles) compared to the evening peak (5935 vehicles), attributable to commuting and educational trips. Consequently, the morning period was selected as the critical case for scenario evaluation.as shown in Figure 3: Level of Service (LOS).



	South	East	North	West	Intersection
LOS	F	F	F	F	F

Figure 3: Level of Service (LOS) Results – Baseline Morning Peak (LOS F for All Approaches)

4.2 Scenario 1: Optimized Fixed-Time Coordination

The first intervention involved optimizing cycle length and green time allocations while retaining fixed-time operation. Cycle time was increased from 130 to 140 seconds with adjusted phase splits.

Results:

- Average delay reduced marginally from 182.2 to 176.8 sec/veh.
- CO_2 emissions decreased from 3080.2 to 3045.1 kg/h (only **1.1% reduction**).
- Fuel consumption reduced from 1232.1 to 1218.1 L/h.
- LOS remained F for all approaches.

This scenario failed to achieve meaningful improvement, confirming that fixed-time optimization alone is insufficient to address the intersection's capacity deficit.

4.3 Scenario 2: Coordinated Actuated Control

The second scenario introduced actuated control with coordinated green phases along the major arterial (Elmukhtar Road and City Center Road). This allowed signal timings to respond dynamically to real-time demand.

Results:

- Average delay reduced to 109.2 sec/veh (40% improvement).
- LOS improved from F to E (approaching D on some approaches).
- CO_2 emissions reduced from 3080.2 to 1870.2 kg/h (**39.3% reduction**).
- Fuel consumption reduced from 1232.1 to 748.1 L/h (**39.3% reduction**).

While this scenario demonstrated substantial environmental benefits, LOS remained below acceptable thresholds (D or better), indicating that signal optimization alone could not fully resolve the capacity constraint.

4.4 Scenario 3: Conversion to Roundabout

The third and final scenario replaced the signalized intersection with a roundabout (50 m diameter, 3 lanes, 3.1 m lane width). This geometric modification fundamentally altered traffic flow patterns by eliminating signal-induced stops and reducing conflicting movements.

Results**:**

Table 4: Sensitivity Analysis Results

Metric	Baseline	Roundabout	Improvement
Average Delay	182.2 sec	22.4 sec	**87.7%**
LOS	F	C	+3 levels
Fuel Consumption	1232.1 L/h	470.9 L/h	**61.8%**
CO_2 Emissions	3080.2 kg/h	1177.4 kg/h	**61.8%**
NOx Emissions	4.847 kg/h	2.725 kg/h	**43.8%**
Degree of Saturation	2.26	0.91	Acceptable

The roundabout scenario delivered the most substantial environmental and operational improvements. CO_2 emissions were reduced by approximately **62%**, representing a saving of 1902.8 kg/h during peak periods. Fuel consumption savings translate to an estimated annual reduction of 1,187,472 liters (based on 6 peak hours/day, 5 days/week, 52 weeks/year), equivalent to approximately 178,120 LYD/year in fuel cost savings.

4.5 Sensitivity Analysis: 10% Traffic Growth

To assess future robustness, a sensitivity test was conducted with a 10% increase in traffic volumes (reflecting projected population growth of 1.16% annually over 10 years).

Results under 10% growth:

Table 5: Sensitivity Analysis Results – 10% Traffic Growth Scenario

Metric	Roundabout (Base)	Roundabout +10%
LOS	C	D
Delay (sec)	22.4	53.2
CO_2 (kg/h)	1177.4	1533.6
Fuel (L/h)	470.9	613.5
Degree of Saturation	0.91	1.15

Even under increased demand, the roundabout maintained acceptable performance (LOS D), with emissions remaining 50% below baseline levels. This confirms the proposed solution's resilience for future traffic growth. Depending on the SIDRA software results before and after modification, the following results show the level of service as presented in Figure 4, 5.

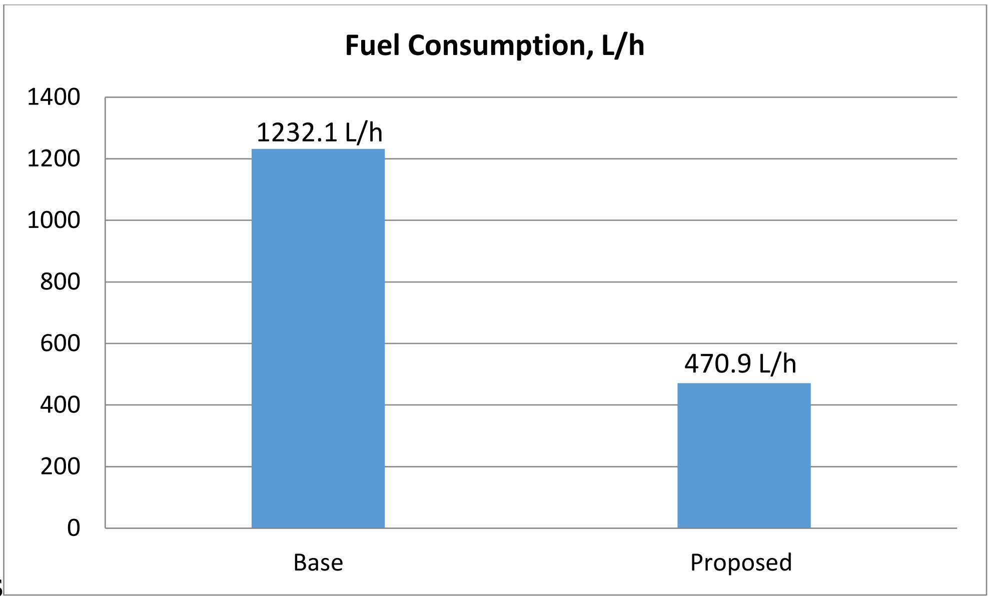


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Figure 4: Comparison between level of fuel (liters per hour)

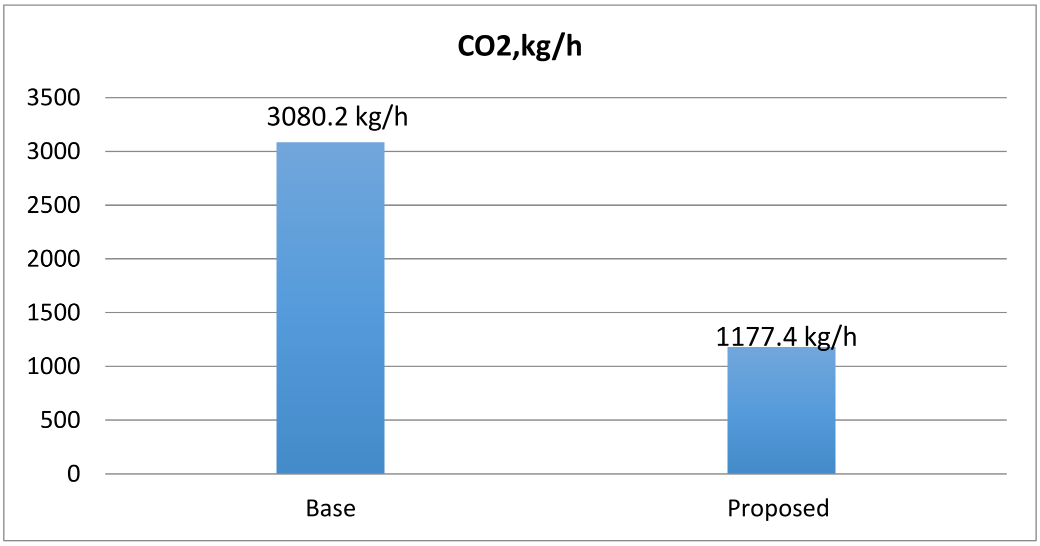

Figure 5: Comparison between level of CO_2 (kg/h)

Table 6 Before and after results

	Base	Proposed
Level of service	F	C
CO_2	3080.2 kg/h	1177.4 kg/h
CO	161.5 kg/h	91.3 kg/h
Delay	182.2 Sec	22.4 Sec
Cost of fuel	1232.1 l/h	470.9 l/h
Degree of Saturation	2.26 v/c ratio	0.91 v/c ratio

4.7 Summary of Findings

Table 7: Comparative Performance of Three Scenarios

Scenario	LOS	Delay (sec)	CO_2 (kg/h)	Fuel (L/h)	vs Baseline
Baseline (Fixed-Time)	F	182.2	3080.2	1232.1	–
Optimized Fixed-Time	F	176.8	3045.1	1218.1	-1.1%
Coordinated Actuated	E	109.2	1870.2	748.1	-39.3%
Roundabout	**C**	**22.4**	**1177.4**	**470.9**	**-61.8%**
Roundabout +10%	D	53.2	1533.6	613.5	-50.2%

The roundabout conversion emerges as the optimal solution, delivering substantial environmental co-benefits alongside operational improvements. The findings demonstrate that geometric redesign can achieve emissions far exceed those attainable through signal optimization alone.

5. Conclusion and Recommendations

5.1 Conclusion

This study evaluated the environmental co-benefits of traffic signal coordination and geometric redesign at the Alhuria intersection in Tobruk, Libya, using SIDRA Intersection 5 software. Three operational scenarios were assessed against baseline fixed-time signal operations: optimized fixed-time coordination, coordinated actuated control, and roundabout conversion.

The baseline conditions revealed severe congestion (LOS F) with average delays of 182.2 sec/veh, fuel consumption of 1232.1 L/h, and CO_2 emissions of 3080.2 kg/h during morning peak periods. While optimized fixed-time coordination produced negligible improvements (1.1% CO_2 reduction), coordinated actuated control achieved a 39.3% reduction in CO_2 emissions and improved LOS from F to E.

The roundabout scenario delivered the most substantial improvements: CO_2 emissions reduced by 61.8% (from 3080.2 to 1177.4 kg/h), fuel consumption reduced by 61.8%, average delay reduced by 87.7% (from 182.2 to 22.4 sec/veh), and LOS improved from F to C. Sensitivity analysis with a 10% traffic growth scenario confirmed the solution's robustness, maintaining acceptable performance (LOS D) with emissions remaining 50% below baseline levels.

The findings demonstrate that geometric redesign—specifically roundabout conversion—offers significant environmental and operational benefits far exceeding those achievable through signal optimization alone. This study contributes empirical evidence from a North African context, addressing a previously underexplored research gap regarding emission reduction potential through intersection redesign in developing cities.

5.2 Recommendations

Based on the study findings, the following recommendations are proposed:

1. **Adopt roundabout conversion** as the preferred solution for the Alhuria intersection, given its substantial environmental and operational benefits, including 62% CO_2 emission reduction and improved LOS from F to C.

2. **Integrate environmental performance metrics** (CO_2, fuel consumption) into traffic management policies in Libyan cities, moving beyond traditional operational measures (delay, LOS) to incorporate sustainability objectives.

3. **Expand data collection** to multiple days and seasons to refine the design at the detailed engineering stage, as current data were limited to one neutral weekday due to COVID-19 constraints.

4. **Promote public transport development** in Tobruk as a complementary long-term strategy to reduce private vehicle dependency and further mitigate urban congestion and emissions.

REFERENCES

[1] Adebambo, S., & Adebayo, I. (2009). Impact of bus rapid transit system (BRT) on passengers' satisfaction in Lagos Metropolis, Nigeria. International Journal of Creativity and Technical Development, 1(3), 106-119.

[2] Akçelik, R. (2005a). Capacity and Performance Analysis of Roundabout Metering Signals. TRB National Roundabout Conference, Vail, Colorado, USA.

[3] Akçelik, R. (2005b). Roundabout Model Calibration Issues and a Case Study. TRB National Roundabout Conference, Vail, Colorado, USA.

[4] Akçelik, R. (2006). Operating cost, fuel consumption and pollutant emission savings at a roundabout with metering signals. ARRB 22nd Conference, Canberra, Australia.

[5] Albalate, D., & Fageda, X. (2019). Congestion, Road Safety, and the Effectiveness of Public Policies in Urban Areas. Sustainability, 11(18), 5092. https://doi.org/10.3390/su11185092

[6] Albrka Ali, S., Reşatoğlua, R., & Tozan, H. (2018). Evaluation and Analysis of Traffic Flow at Signalized Intersections in Nicosia Using of SIDRA 5 Software. Jurnal Kejuruteraan, 30(2), 171-178. https://doi.org/10.17576/jkukm-2018-30(2)-06

[7] Bivina, G., Landge, V., & Kumar, V. S. (2016). Socio Economic Valuation of Traffic Delays. Transportation Research Procedia, 17, 513-520

[8] Darma, Y., Karim, M. R., Mohamad, J., & Abdullah, S. (2005). Control delay variability at signalized intersection based on HCM method. Paper presented at the Proceedings of the eastern Asia society for Transportation Studies

[9] Falcocchio, J., & Levinson, H. (2015). The Costs and Other Consequences of Traffic Congestion. Road Traffic Congestion: A Concise Guide, 159-182. https://doi.org/10.1007/978-3-319-15165-6_13

[10] He, F., Yan, X., Liu, Y., & Ma, L. (2016). A traffic congestion assessment method for urban road networks based on speed performance index. Procedia engineering, 137, 425-433

[11] Mfinanga, D. A. (2014). Ineffective human control of signalised intersections in developing countries; Case of Dar es Salaam city. Transportation Research Part F: Traffic Psychology and Behaviour, 27, 174-181.

[12] Muhammet Mevlüt Akmaz, & Osman Nuri Çelik. (2016). Examination of Signalized Intersections According to Australian and HCM (Highway Capacity Manual) Methods Using Sidra Intersection Software. Journal Of Civil Engineering And Architecture, 10(2). https://doi.org/10.17265/1934-7359/2016.02.013

[13] Oskarbski, J., Guminska, L., Miszewski, M., & Oskarbska, I. (2016). Analysis of signalized intersections in the context of pedestrian traffic. Transportation Research Procedia, 14, 2138-2147.

[14] Said, M. (2016). Determination of Peak Hours And Level Of Service At An Unsignalised Intersection Using aa SIDRA 2.0. IOSR Journal Of Mechanical And Civil Engineering, 13(05), 53-59. https://doi.org/10.9790/1684-1305075359

[15] Tianzi, C., Shaochen, J., & Hongxu, Y. (2013). Comparative Study of VISSIM and SIDRA on Signalized Intersection. Procedia - Social And Behavioral Sciences, 96, 2004-2010. https://doi.org/10.1016/j.sbspro.2013.08.226

[16] Yao, W., Jia, N., Zhong, S., & Li, L. (2018). Best response game of traffic on road network of non-signalized intersections. Physica A: Statistical Mechanics and its Applications, 490, 386-401