

## The Role of Traffic Simulation Software in Assessing Level of Service and Enhancing Road Network Efficiency Synchro as a Case Study

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### دور برامج محاكاة حركة المرور في تقييم مستوى الخدمة وتحسين كفاءة شبكة الطرق: دراسة حالة باستخدام برنامج Synchro

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#### Abstract:

Modern traffic simulation software plays a vital role in advancing transportation and traffic engineering by significantly enhancing network efficiency and operational performance while offering practical solutions to urban mobility challenges. Advanced traffic modeling tools have transformed the planning, design, and operational management of road infrastructure projects. These digital platforms facilitate the detailed representation of roadway geometries and intersections, empowering transportation engineers to rigorously evaluate design alternatives, identify bottlenecks, optimize signal timing, and formulate robust congestion relief strategies. This paper provides a comprehensive analysis of Synchro, a leading traffic modeling and macro/micro-simulation software package. The study explores its practical deployment in modeling traffic flows, determining Level of Service (LOS) parameters, synthesizing alternative geometric and operational interventions, and assessing its contribution to modern traffic engineering. The findings demonstrate that integrating software-driven simulation into traffic evaluation frameworks substantially reduces computational time and financial capital while yielding measurable enhancements in overall network capacity and service quality.

**Keywords** Transportation Engineering, Traffic Simulation, Level of Service (LOS), Synchro Software, SimTraffic, Traffic Congestion, Signal Optimization, Highway Capacity Manual (HCM).

#### المخلص:

تلعب برامج محاكاة حركة المرور الحديثة دورًا محوريًا في تطوير هندسة النقل وهندسة المرور، من خلال تعزيز كفاءة الشبكات والأداء التشغيلي بشكل كبير، إلى جانب توفير حلول عملية للتحديات المرتبطة بالتنقل الحضري. وقد أحدثت أدوات نمذجة حركة المرور المتقدمة تحولًا في أساليب تخطيط وتصميم وإدارة تشغيل مشاريع البنية التحتية للطرق. وتتيح هذه المنصات الرقمية تمثيلًا تفصيليًا للهندسة الهندسية للطرق والتقاطعات، مما يمكن مهندسي النقل من تقييم بدائل التصميم بصورة دقيقة، وتحديد نقاط الاختناق المرورية، وتحسين توقيات الإشارات الضوئية، ووضع استراتيجيات فعالة للحد من الازدحام.

تقدم هذه الورقة تحليلًا شاملاً لبرنامج Synchro ، باعتباره أحد برامج نمذجة ومحاكاة حركة المرور الرائدة، والذي يجمع بين قدرات المحاكاة الكلية والجزئية لحركة المرور (Macro/Micro Simulation) وتركز الدراسة على تطبيقاته العملية في نمذجة تدفقات الحركة المرورية، وتحديد مؤشرات مستوى الخدمة (Level of Service - LOS) ، وتحليل البدائل المختلفة للتدخلات الهندسية والتشغيلية، بالإضافة إلى تقييم مساهمته في تطوير أساليب هندسة المرور الحديثة. وتوضح نتائج الدراسة أن دمج تقنيات المحاكاة المعتمدة على البرمجيات ضمن منهجيات تقييم حركة المرور يساهم بشكل كبير في تقليل الوقت الحسابي والتكاليف المالية اللازمة للتحليل، مع تحقيق تحسينات قابلة للقياس في القدرة الاستيعابية لشبكات الطرق وجودة مستوى الخدمة المقدمة للمستخدمين.

**الكلمات المفتاحية:** : هندسة النقل، محاكاة حركة المرور، مستوى الخدمة ، برنامج Synchro ، برنامج SimTraffic، الازدحام المروري، تحسين الإشارات المرورية، دليل سعة الطرق السريعة .

## Introduction

Roadways constitute the foundational infrastructure enabling human mobility, facilitating the safe, orderly, and timely movement of persons and goods to fulfill daily economic and social activities. Consequently, maintaining the functional integrity, structural safety, and operational performance of road networks represents a paramount priority for transportation authorities and civil engineers [1].

The empirical analysis of traffic volumes forms a cornerstone of traffic and highway engineering. Traffic volume studies involve the systematic collection and quantification of vehicle counts passing a designated cross-section or intersection over specified temporal intervals, typically capturing peak-hour conditions. From an engineering standpoint, informed decision-making regarding geometric design, lane configurations, and traffic control devices cannot be achieved without accurate evaluations of existing and projected operational capacities. Furthermore, traffic studies enable transportation professionals to diagnose network performance, locate structural bottlenecks, and determine the Level of Service (LOS) across major corridors [2] utilizing field surveys, office analytics, and dynamic simulation methodologies.

Understanding the functional and operational dynamics of urban arterials and freeways requires a holistic examination of the complex interactions among primary system components. Traffic flow characteristics are governed by five key elements: road users (drivers and pedestrians), vehicle fleets (mix of light and heavy vehicles), geometric roadway designs, traffic control mechanisms (signals, signage, and markings), and ambient environmental factors.

Computer-based traffic simulation was first introduced to address urban traffic management in the 1950s, providing a virtual testbed to evaluate the effectiveness of proposed transportation strategies prior to physical execution. Today, advanced traffic modeling platforms—such as Synchro and SimTraffic—enable traffic engineers to model real-world dynamic flow patterns, signal timing interactions, and complex intersection geometries. These software-driven analytical frameworks provide precise macroscopic capacity assessments and microscopic behavioral evaluations. By replacing or supplementing traditional manual calculation protocols, modern simulation platforms allow transportation planners to quantitatively evaluate alternative design scenarios, optimize signal coordination, mitigate localized congestion, and verify project feasibility and operational safety before committing significant financial and physical resources [4].

This paper investigates the functional capabilities of the Synchro platform, examining its methodology for calculating LOS, generating alternative traffic management strategies, and advancing modern traffic engineering practices while optimizing computational time and economic resources.

### 1.1 Level of Service (LOS) on Highways and Intersections

Level of Service (LOS) is a standardized qualitative measure used to describe operational conditions within a traffic stream and their perception by motorists. The metric categorizes traffic performance into six discrete levels, designated alphabetically from LOS A (free-flow) to LOS F (breakdown/forced flow). LOS evaluates driver comfort, freedom to maneuver, operating speed, and total control delay. Mathematically, LOS is closely linked to the Volume-to-Capacity ratio (V/C), defined as:

$$V/C \text{ Ratio} = \text{Volume (V)} / \text{Capacity (C)}$$

Additionally, LOS accounts for factors such as travel time, freedom to pass, driving safety, and operating expenses [4]. Table 1 summarizes the operational criteria and delay thresholds defining each LOS designation according to international standards:

**Table 1: Operational Characteristics and Delay Thresholds for Level of Service (LOS)**

| Level of Service (LOS) | Volume-to-Capacity Ratio (V/C) | Operational Characteristics and Flow Conditions                                                                                                                                                                  | Control Delay (sec/veh) |
|------------------------|--------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------|
| <b>A</b>               | < 0.60                         | Free-flow operations. High driver comfort and excellent maneuverability. Average travel speed is approximately 90% of free-flow speed. Minimal delay at signalized intersections.                                | 0 – 10                  |
| <b>B</b>               | 0.60 – 0.70                    | Reasonably free flow. High comfort with slight restrictions in maneuverability. Travel speeds drop to ~70% of free-flow speed due to intersection interactions. Load factor ~0.10, Peak Hour Factor (PHF) ~0.80. | 11 – 20                 |
| <b>C</b>               | 0.70 – 0.80                    | Stable flow condition. Acceptable maneuverability, with average travel speed around 50% of free-flow speed. Formation of noticeable queues at signalized approaches.                                             | 21 – 35                 |
| <b>D</b>               | 0.80 – 0.90                    | Approaching unstable flow. Driver discomfort increases as maneuverability becomes severely restricted. Travel speed ~40% of free-flow speed; substantial delay at signalized junctions.                          | 36 – 55                 |
| <b>E</b>               | 0.90 – 1.00                    | Unstable flow at or near full roadway capacity. Severe maneuverability restrictions; travel speed ~33% of free-flow speed. High load factor (0.70–1.00) and PHF ~0.95. Long queues and congestion.               | 56 – 80                 |
| <b>F</b>               | > 1.00                         | Forced or breakdown flow. Demand exceeds capacity (V/C > 1.0). Travel speeds drop below 25–33% of free-flow speed, accompanied by extreme delays and stop-and-go conditions.                                     | > 80                    |

## 1.2 Traffic Volume

Traffic Volume (V) is defined as the total number of vehicles passing a designated point or section of a lane/roadway per unit time. It is expressed in units of vehicles per unit time (e.g., vehicles per day, hour, or 15-minute interval). In traffic design, volume is conventionally expressed as vehicles per hour (veh/h) [2].

## 1.3 Roadway Capacity

Roadway Capacity (C) represents the maximum sustainable hourly rate at which vehicles can reasonably be expected to traverse a point or uniform segment of a lane or roadway under prevailing roadway, traffic, and control conditions. Design capacity accounts for projected traffic demand and exceeds current operational volumes to ensure long-term stability. Total directional capacity is formulated as:

$$C = \text{Lane Capacity} \times N$$

Where:

**Lane Capacity:** Base saturation flow or ideal capacity of a single lane, typically ranging between 1,900 and 2,200 passenger cars per hour per lane (pc/h/ln) under ideal conditions per the Highway Capacity Manual (HCM).

**N:** Number of physical travel lanes provided in a single direction.

## 2. CONVENTIONAL MANUAL CALCULATION OF LEVEL OF SERVICE

Manual evaluation procedures require systematic empirical data collection. Traffic counts are conducted over multiple days (e.g., Sunday through Thursday) to establish average weekday volume distributions and peak flow patterns.

## 2.1 Estimation of Peak Hour Factor (PHF) and Peak Hour Volume (PHV)

Field counting is executed at 10- to 15-minute intervals during anticipated peak demand windows. To identify the absolute Peak Hour Volume (PHV), consecutive sub-interval counts are aggregated in a moving hourly window. The Peak Hour Factor (PHF) quantifies flow rate variability within the peak hour and is calculated as follows:

$$PHF = V_{\text{hourly}} / (4 \times V_{15})$$

Where  $V_{\text{hourly}}$  is the total volume during the peak hour (veh/h), and  $V_{15}$  is the maximum traffic volume recorded during a single 15-minute interval within that peak hour. Future design volumes are projected using annual growth rate assumptions (e.g., 2% annual compound growth over a 15-year design horizon).

## 2.2 Step-by-Step Manual Assessment Procedure

The standard manual protocol for evaluating roadway corridors and intersections follows ten structured steps:

- 1. Site Selection:** Delineate the geometric boundaries of the study corridor or intersection.
- 2. Traffic Counting:** Perform comprehensive field surveys to tally movement-specific vehicle volumes.
- 3. Peak Hour Identification:** Determine the highest-volume 60-minute window from empirical data.
- 4. Traffic Composition Analysis:** Classify vehicles (passenger cars, heavy buses, trucks) and convert counts to equivalent Passenger Car Units (PCUs).
- 5. Parameter Calculation:** Compute Peak Hour Volume (PHV), Peak Hour Factor (PHF), and Design Hourly Volume (DHV).
- 6. Baseline Performance Evaluation:** Determine directional capacity (C), baseline V/C ratios, initial LOS, and Service Flow rates (SF).
- 7. Formulation of Mitigation Measures:** Propose geometric modifications or signal timing adjustments if baseline performance is unsatisfactory (e.g., LOS E or F).
- 8. Re-evaluation of Proposed Mitigation:** Recompute capacity, delays, and LOS incorporating the proposed engineering modifications.
- 9. Comparative Performance Analysis:** Compare key performance metrics (delays, queue lengths, LOS) between baseline and mitigated conditions.
- 10. Final Recommendation:** Select and recommend the optimal engineering intervention for field implementation.

## 3. SOFTWARE-DRIVEN TRAFFIC MODELING AND SIMULATION FRAMEWORKS

Since its inception in the 1950s, traffic simulation has evolved into an indispensable tool for verifying engineering designs before physical deployment. Software packages like Synchro model complex dynamic interactions, evaluating operational metrics and validating proposed traffic management schemes in a virtual environment [4].

### 3.1 Synchro Software Platform

Synchro is a macro/microscopic software package designed to analyze, optimize, and evaluate traffic operations along individual intersections, arterial corridors, and complex highway networks. The software assists traffic engineers in testing operational and geometric modifications, including signal re-timing, phase sequence changes (e.g., lead/lag left-turn phases), lane reallocations, and corridor coordination.

Widely adopted in professional traffic engineering, Synchro combines an intuitive graphical user interface (GUI) with robust computational engines based on standardized analytical methodologies. It produces clear diagnostic reports and allows real-time dynamic simulation of existing and proposed network conditions. Performance evaluation focuses primarily on vehicle

control delay, queue accumulation, and corresponding LOS classifications across individual lane groups and overall junctions.

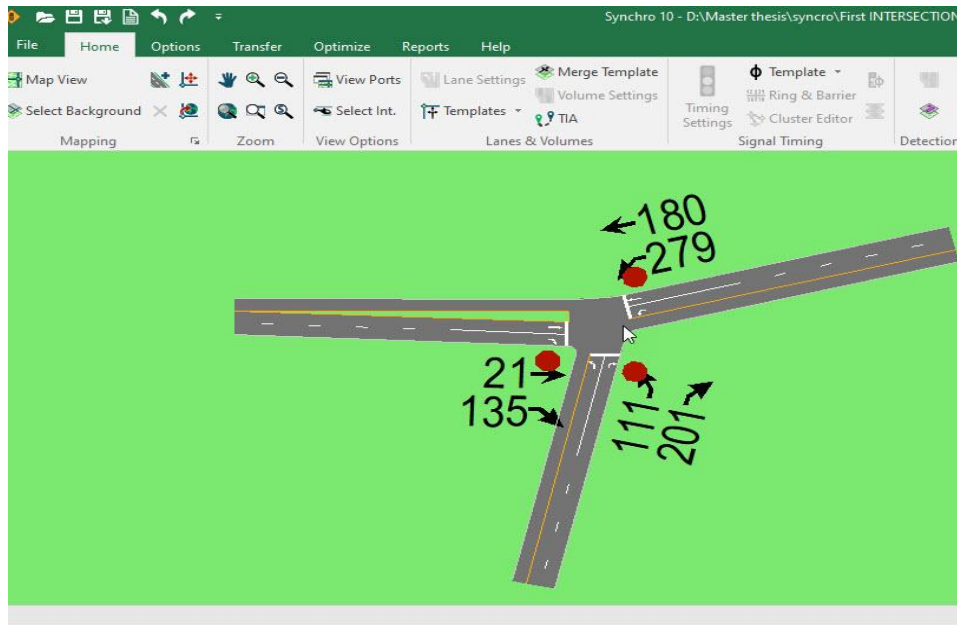


**Figure 1:** Synchro User Interface and Main Workspace Layout

### 3.2 Highway Capacity Manual (HCM 2000) Methodology Integration

Synchro fully incorporates the analytical procedures defined in the Highway Capacity Manual (HCM 2000). Table 2 details the core input parameters and resultant diagnostic outputs within the software environment:

**Table 2: Input Data Categories and Diagnostic Output Metrics in Synchro**

| Input Category                                   | Required Data Elements                                                                                                                                                                                                    | Primary Output & Diagnostic Metrics                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|--------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Geometric Settings (Lane Settings)</b>        | Number of travel lanes per approach, lane widths, approach grades, storage bay lengths (turn pockets), link lengths, free-flow speeds, and added acceleration/deceleration lanes.                                         | <ul style="list-style-type: none"> <li>• Capacity Analysis: Calculated approach capacity and Volume-to-Capacity (V/C) ratios.</li> <li>• Delay Metrics: Average control delay per vehicle (sec/veh).</li> <li>• Service Quality: Level of Service (LOS) designation per lane group, approach, and intersection.</li> <li>• Queue Estimation: 50th percentile and 95th percentile queue lengths.</li> <li>• Arterial Coordination: Signal progression optimization, bandwidth, and green wave alignment.</li> </ul> |
| <b>Traffic Flow Settings (Volume Settings)</b>   | Ideal saturation flow rate, turning movement volumes (vph), pedestrian counts, bicycle volumes, Peak Hour Factor (PHF), percentage of heavy vehicles (%HV), bus stop frequencies, and parking maneuver frequencies.       |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| <b>Signal Control Settings (Signal Settings)</b> | Controller type (actuated, pre-timed, coordinated), cycle length, phase sequencing/templates, green split allocations, yellow change intervals, all-red clearance intervals, and pedestrian walk/flash-don't-walk splits. |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |

### 3.3 Model Setup and Data Entry Protocol

The model building workflow in Synchro follows a systematic setup protocol. Upon importing empirical field data, the user configures regional parameters (e.g., metric units). The software supports aerial imagery overlays, enabling accurate georeferenced scaling of roads, lane alignments, and junction geometries. Road segments are generated using the Add Link tool to construct the network topology, after which lane configurations, turning movement volumes, and control parameters are populated across all approaches.

### 3.4 Microscopic Simulation and Report Generation via SimTraffic

Following macroscopic optimization in Synchro, micro-level operational performance is modeled using SimTraffic, an integrated microscopic simulation tool. SimTraffic utilizes Synchro link-node geometries and traffic parameters to simulate individual vehicle movements, driver behavior, lane-changing dynamics, and car-following interactions. This visual simulation enables engineers to observe traffic operations, identify localized friction points, and visually validate proposed geometric or signal modifications.

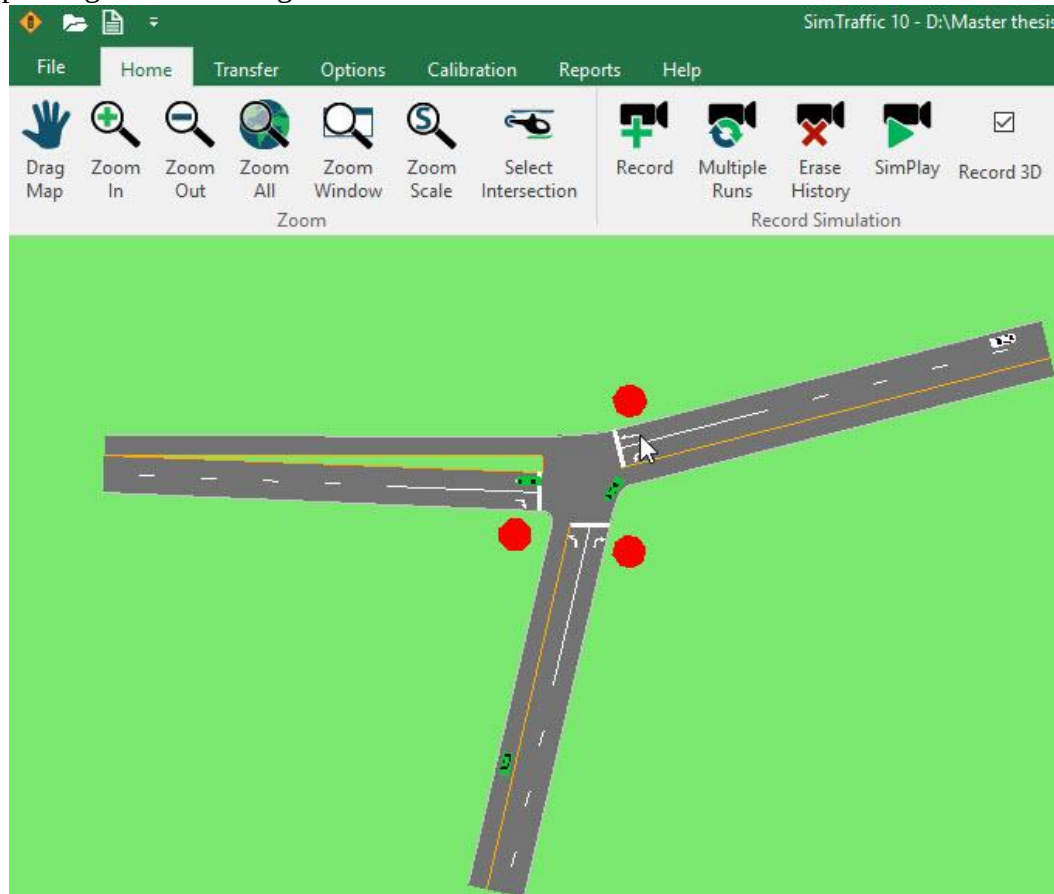


**Figure 2:** SimTraffic Microscopic Simulation Environment

Following simulation runs, comprehensive diagnostic reports are synthesized via the Create Report utility. These reports output quantitative performance metrics—including average delays, travel times, V/C ratios, queue spillbacks, and overall intersection LOS—providing a solid empirical foundation for engineering decisions.

|                                   |              |       |       |                        |       |       |
|-----------------------------------|--------------|-------|-------|------------------------|-------|-------|
|                                   | →            | ↘     | ↙     | ←                      | ↖     | ↗     |
| Lane Group                        | EBT          | EBR   | WBL   | WBT                    | NBL   | NBR   |
| Lane Configurations               | ↑            | ↗     | ↘     | ↑                      | ↘     | ↗     |
| Traffic Volume (vph)              | 21           | 135   | 279   | 180                    | 111   | 201   |
| Future Volume (vph)               | 21           | 135   | 279   | 180                    | 111   | 201   |
| Ideal Flow (vphpl)                | 1900         | 1900  | 1900  | 1900                   | 1900  | 1900  |
| Lane Util. Factor                 | 1.00         | 1.00  | 1.00  | 1.00                   | 1.00  | 1.00  |
| Ped Bike Factor                   |              |       |       |                        |       |       |
| Frt                               |              | 0.850 |       |                        |       | 0.850 |
| Flt Protected                     |              |       | 0.950 |                        | 0.950 |       |
| Satd. Flow (prot)                 | 1883         | 1601  | 1789  | 1883                   | 1789  | 1601  |
| Flt Permitted                     |              |       | 0.950 |                        | 0.950 |       |
| Satd. Flow (perm)                 | 1883         | 1601  | 1789  | 1883                   | 1789  | 1601  |
| Link Speed (k/h)                  | 48           |       |       | 48                     | 48    |       |
| Link Distance (m)                 | 94.8         |       |       | 90.8                   | 84.6  |       |
| Travel Time (s)                   | 7.1          |       |       | 6.8                    | 6.3   |       |
| Confl. Peds. (#/hr)               |              | 5     | 10    |                        | 2     | 2     |
| Peak Hour Factor                  | 0.92         | 0.92  | 0.92  | 0.92                   | 0.92  | 0.92  |
| Adj. Flow (vph)                   | 23           | 147   | 303   | 196                    | 121   | 218   |
| Shared Lane Traffic (%)           |              |       |       |                        |       |       |
| Lane Group Flow (vph)             | 23           | 147   | 303   | 196                    | 121   | 218   |
| Enter Blocked Intersection        | No           | No    | No    | No                     | No    | No    |
| Lane Alignment                    | Left         | Right | Left  | Left                   | Left  | Right |
| Median Width(m)                   | 3.7          |       |       | 3.7                    | 3.7   |       |
| Link Offset(m)                    | 0.0          |       |       | 0.0                    | 0.0   |       |
| Crosswalk Width(m)                | 1.6          |       |       | 1.6                    | 1.6   |       |
| Two way Left Turn Lane            |              |       |       |                        |       |       |
| Headway Factor                    | 0.99         | 0.99  | 0.99  | 0.99                   | 0.99  | 0.99  |
| Turning Speed (k/h)               |              | 14    | 24    |                        | 24    | 14    |
| Sign Control                      | Stop         |       |       | Stop                   | Stop  |       |
| Intersection Summary              |              |       |       |                        |       |       |
| Area Type:                        | Other        |       |       |                        |       |       |
| Control Type:                     | Unsignalized |       |       |                        |       |       |
| Intersection Capacity Utilization | 35.4%        |       |       | ICU Level of Service A |       |       |
| Analysis Period (min)             | 15           |       |       |                        |       |       |

**Figure 3:** Synchro HCM Intersection Capacity and Level of Service (LOS) Diagnostic Report

#### 4. OPERATIONAL AND GEOMETRIC ENGINEERING SOLUTIONS IN SYNCHRO

Synchro allows engineers to evaluate a spectrum of operational (low-cost) and geometric (capital-intensive) mitigation strategies:

- 1. Operational Strategies (Traffic Control & Signalization):** These represent cost-effective measures aimed at optimizing existing infrastructure. Interventions include converting unsignalized junctions to signalized control, re-optimizing cycle lengths, re-allocating green splits, adjusting phase sequences, coordinating adjacent controllers along arterials (green wave progression), or prohibiting specific high-conflict turning movements (e.g., restricting left turns during peak hours).
- 2. Geometric Engineering Strategies (Infrastructure Modifications):** These involve structural modifications to roadway geometry, such as installing roundabouts, modifying island radii, introducing dedicated turn lanes (left/right-turn pockets), extending storage bay lengths, widening approach legs, or constructing grade-separated interchanges.

#### 5. CASE STUDY – EVALUATION OF CIVIL DEFENCE INTERSECTION (BANI WALID CITY)

##### 5.1 Site Description & Geometric Configuration

The Civil Defence Intersection is a major four-leg signalized junction located in central Bani Walid City. The North-South corridor (Links C & D) serves as a primary arterial connecting the city center to the Tripoli highway (North) and Mizdah highway (South). The East-West corridor (Links A & B) links dense residential zones (Al-Dhar) to the Industrial District.

Adjacent high-density land-use facilities—including schools, colleges, and medical complexes—generate heavy local traffic and roadside parking friction.

The geometric features of the intersection legs are summarized in Table 3:

**Table 3: Geometric Characteristics of the Intersection**

| Leg / Link     | Number of Lanes | Lane Width (m) | Markings & Signage Status      |
|----------------|-----------------|----------------|--------------------------------|
| Link A (West)  | 4               | 3.6            | Good pavement markings         |
| Link B (East)  | 2               | 3.6            | Missing markings / Unregulated |
| Link C (South) | 2               | 3.6            | Missing markings / Unregulated |
| Link D (North) | 2               | 3.6            | Signage requires maintenance   |

### 5.2 Traffic Characteristics & Baseline Assessment (Existing Condition)

Traffic volume counts reveal significant directional split asymmetry due to regional freight and transit movement along the North-South axis. Baseline modeling in Synchro evaluated the existing 4-phase pre-timed signal timing (Cycle Length = 120s).

**Table 4: Synchro Baseline Traffic Inputs & Signal Settings**

| Parameter                      | Link A (EB) | Link B (WB) | Link C (NB) | Link D (SB) |
|--------------------------------|-------------|-------------|-------------|-------------|
| Traffic Volume (vph)           | 123         | 138         | 323         | 333         |
| Peak Hour Factor (PHF)         | 0.92        | 0.92        | 0.92        | 0.92        |
| Adjusted Flow (vph)            | 214         | 241         | 562         | 580         |
| Heavy Vehicles (%)             | 1%          | 2%          | 3%          | 3%          |
| Pedestrian Conflicts (peds/hr) | 55          | 55          | 42          | 24          |
| Baseline Phase Split (s)       | 20.0        | 21.0        | 56.0        | 23.0        |

#### Baseline Assessment Results:

The operational evaluation of the existing signal timing revealed severe congestion:

- **Overall Intersection LOS:** LOS F
- **Average Control Delay:** 114.2 sec/veh
- **Maximum Volume-to-Capacity (v/c) Ratio:** 1.79 (Critical Over-saturation on SB/NB movements)

### 5.3 Mitigation Alternatives & Optimization Results

To mitigate the delay and enhance capacity, three progressive engineering alternatives were evaluated using Synchro:

#### Alternative 1: Signal Green-Split Re-allocation

Green times were re-allocated without changing the total cycle length (Cycle Length = 120s) to give more green time to the heavy North-South arterial movements (SB/NB split extended to 37s each).

- **Results:** Overall delay dropped to 75.0 sec/veh, improving the intersection service level to LOS E. However, NB and EB straight movements remained at LOS F.

#### Alternative 2: Channelization & Right-Turn Free Flow Optimization

Right-turn movements across all legs were converted to un-signalized Channelized Free-Flow movements. Left-turn phases were re-grouped into permitted/protected opposing combinations.

- **Results:** Delay was further reduced to 65.5 sec/veh (LOS E), with substantial approach-level improvements across Eastbound and Westbound movements (both improved to LOS C).

### Alternative 3: Cycle Length Extension & Phasing Fine-Tuning (Optimal Solution)

To clear the residual left-turn queues on the Northbound approach (NBL), the total cycle length was extended from 120s to 127s (Phasing splits: Phase 1=25s, Phase 2=25s, Phase 3=37s, Phase 4=40s).

- **Results:** The intersection achieved an acceptable operational performance:
  - **Overall Intersection LOS:** LOS D
  - **Average Control Delay:** 40.7 sec/veh (a 64.4% reduction from baseline)
  - **Max v/c Ratio:** Reduced from 1.79 to 0.81

### 5.4 Summary of Alternatives Comparison

Table 5: Operational Comparison of Evaluated Scenarios

| Performance Metric           | Baseline (Existing) | Alternative 1 (Split Adjustment) | Alternative 2 (Free Right Turns) | Alternative 3 (Optimal Timing) |
|------------------------------|---------------------|----------------------------------|----------------------------------|--------------------------------|
| Cycle Length (s)             | 120                 | 120                              | 120                              | 127                            |
| Intersection Delay (sec/veh) | 114.2               | 75.0                             | 65.5                             | 40.7                           |
| Intersection LOS             | LOS F               | LOS E                            | LOS E                            | LOS D                          |
| Max v/c Ratio                | 1.79                | 1.79                             | 1.79                             | 0.81                           |
| ICU Capacity Utilization     | 48.3% (LOS A)       | 48.3% (LOS A)                    | 48.3% (LOS A)                    | 45.8% (LOS A)                  |

### Conclusions And Recommendations

This study underscores the pivotal role of computer-aided modeling and simulation tools, specifically Synchro and SimTraffic, in streamlining traffic engineering workflows, reducing analytical expenditure, and evaluating corridor performance. The practical application to the Civil Defence Intersection in Bani Walid City clearly demonstrates the efficiency of software-driven optimization over traditional manual assessments.

Based on the empirical findings and comparative operational evaluations, the following core conclusions and engineering recommendations are established:

- **Significant Operational Gains:** Implementing optimized signal timing and geometric modifications yielded substantial performance enhancements. The optimal scenario (Alternative 3) successfully reduced the average intersection control delay from **114.2 sec/veh to 40.7 sec/veh**—representing a **64.4% reduction in overall delay**—while bringing the maximum volume-to-capacity (v/c) ratio down from **1.79 to 0.81** and improving the overall Level of Service from **LOS F to LOS D**.
- **Prioritizing Low-Cost Signal Optimization:** Operational traffic control adjustments—such as cycle length extensions, phase split re-allocations, and channelized free-right turns—must be prioritized prior to committing to capital-intensive physical infrastructure modifications.
- **Engineering Judgment Beyond Baseline Metrics:** While establishing baseline LOS is straightforward with reliable field data, formulating site-specific, high-impact mitigation strategies requires deep engineering insight into localized corridor dynamics to target critical movements operating at poor service levels (LOS E/F).

- **Comprehensive Feasibility Audits:** Before executing physical intersection expansions or roundabout constructions, thorough site audits must evaluate right-of-way (ROW) constraints, land acquisition costs, urban fabric impacts, and potential underground utility conflicts (e.g., water mains, electrical networks).
- **Network-Wide Delays Monitoring:** Mitigation strategies must be designed holistically to ensure that resolving congestion at a specific junction improves overall arterial progression rather than transferring bottlenecks to adjacent intersections.

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