

# Signal Timing Optimization for Urban Arterials Based on Entropy-Weighted TOPSIS Comprehensive Evaluation

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**Abstract:** To address recurrent queues and delays caused by uneven traffic demand on urban arterials and the mismatch between fixed intersection signal timings and actual vehicle arrivals, this study proposes a signal timing optimization method based on entropy-weighted TOPSIS comprehensive evaluation. The continuous signalized corridor of Beixin East Road from Jianshe Road to Binhe Road in Tangshan is taken as the study area. Without introducing multi-source data fusion, a unified evaluation system is constructed directly from the road network, traffic demand, and SUMO simulation outputs. First, 59 OD demands are established according to road functional hierarchy, approach-lane capacity, turning structure, and node flow conservation, with a total external demand of 4470 veh/h. Average travel time, average waiting time, average time loss, and average queue length are then selected as the core performance indicators. Information entropy is used to determine objective weights, and TOPSIS relative closeness is employed to evaluate signal timing schemes. On this basis, an offline feedback optimization process of evaluation, diagnosis, adjustment, and re-evaluation is developed. While maintaining the original phase sequence and safety transition times, the coordinated cycle of the major intersections in the corridor is unified to 110 s, and effective green times are redistributed according to critical flow ratios. SUMO 1.27.1 simulations show that, compared with the original timing scheme, the optimized scheme reduces average travel time from 352.35 s to 334.12 s, average waiting time from 240.12 s to 220.31 s, and average time loss from 311.86 s to 294.04 s, corresponding to improvements of 5.18%, 8.25%, and 5.71%, respectively. The average queue length increases from 72.78 m to 79.47 m, indicating a local spatial redistribution of queues while temporal costs are reduced by the common-cycle and green-split reconstruction. In the entropy-weighted TOPSIS evaluation, the relative closeness increases from 0.4978 to 0.5022. The results demonstrate that the proposed method avoids judging signal timing performance using a single indicator and provides a reproducible technical route for multi-indicator optimization and simulation-based evaluation of urban arterial signal timing.

**Keywords:** Urban Traffic Congestion; Signal Timing; Entropy Weighting; SUMO.

## 1. Introduction

With the growth of urban motor-vehicle travel demand, signalized intersections have gradually become key constraints on urban road operating efficiency. For continuous urban arterials, unreasonable signal timing at a single intersection not only increases local delay but can also propagate upstream and downstream through queue spillback, platoon dispersion, and cycle incompatibility, producing a chain effect of local queuing, arterial blockage, and reduced regional efficiency. Public information released by the traffic management authority of Tangshan also indicates that, under road-construction diversions and changes in traffic demand, signal timing on some roads in the central urban area requires continuous adjustment and optimization to alleviate local congestion. [10] Therefore, without large-scale road expansion, improving the utilization efficiency of existing road resources by optimizing signal cycles and green splits remains of considerable engineering value.

Classical fixed-time signal timing theory is represented by the Webster method, which determines cycle length and green-time allocation using critical lane-group flow ratios and lost time, thereby laying the foundation for signal-control design [12]. With the development of microscopic traffic simulation and intelligent optimization techniques, signal timing research has gradually shifted from isolated intersections and single objectives toward arterial corridors and multiple objectives, including connected-vehicle and

dynamic-control settings [13]. SUMO is open-source, programmable, and capable of producing vehicle-level operating indicators, and has therefore been widely used to verify signal-control schemes [2, 6]. Recent studies further show that multi-objective optimization can simultaneously consider delay, number of stops, queues, energy consumption, and other indicators. However, because the dimensions and optimization directions of different indicators are inconsistent, empirical weighting can introduce subjectivity [7, 8, 11].

Information entropy can objectively determine indicator weights from the dispersion of indicator samples [9], while TOPSIS evaluates overall performance by measuring the distances between each alternative and the positive and negative ideal solutions [5]. Entropy-weighted TOPSIS has been applied to urban road-network operating performance and comprehensive transportation-system evaluation, demonstrating good multi-indicator ranking capability [1, 4]. Compared with signal timing approaches that use average delay as the sole objective, the main objectives of this study are: (1) to reduce the influence of subjective weighting by using the entropy-weight method; (2) to use TOPSIS to consider both temporal efficiency and spatial queues, preventing improvement in one indicator from masking deterioration in another; (3) to use a common coordinated cycle and critical flow ratios as the principal adjustment variables while maintaining the existing phase-conflict relationships, thereby reducing implementation complexity; and (4) to perform microscopic simulations of the entire

process before and after optimization using SUMO and report both improved and deteriorated indicators so that the results remain interpretable.

## 2. Study Area and Data Construction

### 2.1. Study Area

The study area is the east-west urban arterial corridor of Beixin East Road between Jianshe Road and Binhe Road in Tangshan. The existing SUMO [3] road network contains seven major signal-controlled nodes: Jianshe Road, Wenhua Road, Longze Road, Dacheng Road, Hexi Road, the east-side branch road, and Binhe Road. The study does not change the road geometry or phase-conflict relationships; only the signal cycle lengths and effective green times are optimized. This treatment decouples network-structure changes from timing changes, so that the performance differences before and after

optimization mainly originate from signal-control parameters.

### 2.2. Data Sources

The traffic demand is not based on measured turning volumes for every approach collected by the traffic-management authority; instead, synthetic traffic demand is constructed for methodological verification. The basic principles are that traffic demand on the arterial is higher than that on ordinary side roads; the total flow at each approach satisfies conservation among left-turn, through, and right-turn components; and each OD route is checked against SUMO edge, connection, and lane-permission constraints. The data can therefore be used to compare the relative performance of different signal timing schemes under controlled conditions, but the total demand of 4470 veh/h is not presented as the measured traffic volume for a specific time period on Beixin East Road. Table 1

Table 1. Major road-entry traffic demand.

| Road                  | Approach direction | Hourly traffic volume / (veh·h <sup>-1</sup> ) |
|-----------------------|--------------------|------------------------------------------------|
| Beixin East Road      | W → E              | 700                                            |
| Beixin East Road      | E → W              | 650                                            |
| Jianshe Road          | South approach     | 420                                            |
| Jianshe Road          | North approach     | 400                                            |
| Wenhua Road           | South approach     | 260                                            |
| Wenhua Road           | North approach     | 240                                            |
| Longze Road           | South approach     | 360                                            |
| Longze Road           | North approach     | 340                                            |
| Dacheng Road          | South approach     | 120                                            |
| Hexi Road             | South approach     | 140                                            |
| East-side branch road | South approach     | 200                                            |
| East-side branch road | North approach     | 180                                            |
| Binhe Road            | Northwest approach | 220                                            |
| Binhe Road            | Southeast approach | 240                                            |

### 2.3. SUMO Simulation Settings

To ensure comparability of the results, SUMO 1.27.1 is used for the simulations (DLR, 2026). All schemes use the same road network, the same OD demand, and the same vehicle composition. The total simulation duration is 4200 s. Traffic demand is continuously loaded from 0 to 3600 s, after which no new demand is generated from 3600 to 4200 s so that vehicles remaining in the network can dissipate.

## 3. Entropy-Weighted TOPSIS Evaluation and Signal Timing Optimization Method

### 3.1. Indicator System

Considering the combined effect of signal control on vehicle time costs and spatial queuing, average travel time  $T$ , average waiting time  $W$ , average time loss  $L_t$ , and average queue length  $Q_l$  are selected as the core evaluation indicators. All four indicators are cost-type indicators, i.e., a smaller value indicates a better operating condition. The cumulative number of arrived vehicles is analyzed separately as an auxiliary capacity indicator and is not included in the main TOPSIS evaluation matrix, so as to avoid assigning excessive weight to small end-of-simulation vehicle-count differences when the total demand is fixed.

### 3.2. Indicator Normalization

Because the evaluation indicators have different

dimensions and numerical ranges, direct comprehensive evaluation may cause indicators with larger numerical magnitudes to dominate the result. Therefore, vector normalization is first applied to the original decision matrix  $X = (x_{ij})$  to obtain dimensionless values:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^m x_{ij}^2}} \quad (1)$$

where  $x_{ij}$  is the original value of the  $j$ -th evaluation indicator for the  $i$ -th signal timing scheme;  $r_{ij}$  is the normalized indicator value;  $i = 1, 2, \dots, m$  and  $j = 1, 2, \dots, n$ ;  $m$  is the number of signal timing schemes; and  $n$  is the number of evaluation indicators. For cost-type indicators, the minimum value is directly taken as the positive ideal state when the TOPSIS ideal solutions are determined, so the original physical meaning of the indicators does not need to be changed.

### 3.3. Entropy Weight Determination

The entropy-weight method determines objective weights from the degree of variation of each indicator among the evaluated schemes. A larger difference in an indicator across schemes implies a greater amount of information and a stronger ability to distinguish among schemes. The contribution of each scheme to an indicator is first calculated as:

$$p_{ij} = \frac{r_{ij}}{\sum_{i=1}^m r_{ij}} \quad (2)$$

where  $p_{ij}$  is the contribution or characteristic proportion of the  $i$ -th signal timing scheme under the  $j$ -th evaluation indicator.

The information entropy of the  $j$ -th indicator is then calculated as:

$$e_j = -k \sum_{i=1}^m p_{ij} \ln p_{ij}, \quad k = \frac{1}{\ln m} \quad (3)$$

where  $e_j$  is the information entropy of the  $j$ -th evaluation indicator,  $k$  is the entropy normalization coefficient, and  $\ln(\cdot)$  denotes the natural logarithm. When  $p_{ij} = 0$ ,  $p_{ij} \ln p_{ij}$  is taken as 0.

Defining the information redundancy as  $d_j = 1 - e_j$ , the objective weight of the  $j$ -th indicator is:

$$w_j = \frac{d_j}{\sum_{j=1}^n d_j} \quad (4)$$

where  $w_j$  is the entropy weight of the  $j$ -th evaluation indicator and  $n$  is the total number of indicators. The weights satisfy  $\sum w_j = 1$ . This weighting method does not rely on subjective expert scoring and is therefore suitable for comprehensive evaluation across different traffic-performance indicators.

### 3.4. TOPSIS Comprehensive Evaluation

The entropy weights are multiplied by the normalized matrix to obtain the weighted decision matrix  $V = (v_{ij})$ :

$$v_{ij} = w_j r_{ij} \quad (5)$$

where  $v_{ij}$  is the weighted normalized value of the  $j$ -th evaluation indicator for the  $i$ -th signal timing scheme.

For the cost-type indicators used in this study, the positive ideal solution  $A^+$  takes the minimum value in each column,  $v_j^+ = \min(v_{ij})$ , whereas the negative ideal solution  $A^-$  takes the maximum value in each column,  $v_j^- = \max(v_{ij})$ . The Euclidean distances from scheme  $i$  to the positive and negative ideal solutions are, respectively:

$$D_i^+ = \sqrt{\sum_{j=1}^n (v_{ij} - v_j^+)^2} \quad (6)$$

$$D_i^- = \sqrt{\sum_{j=1}^n (v_{ij} - v_j^-)^2} \quad (7)$$

where  $D_i^+$  and  $D_i^-$  denote the Euclidean distances from the  $i$ -th scheme to the positive and negative ideal solutions, respectively. The relative closeness is defined as:

$$C_i = \frac{D_i^-}{D_i^+ + D_i^-} \quad (8)$$

where  $C_i$  is the TOPSIS relative closeness of the  $i$ -th signal timing scheme, with  $0 \leq C_i \leq 1$ . A larger  $C_i$  indicates that the timing scheme is closer to the comprehensive ideal operating state.

### 3.5. Signal Timing Feedback Optimization

The evaluation model described above is embedded in the signal timing adjustment process to form an offline iterative framework of evaluation, diagnosis, adjustment, and re-evaluation. Specifically, the original signal timing scheme is first simulated and the four indicators are calculated. Entropy-weighted TOPSIS is then used to identify overall performance and the main shortcomings. Next, the common cycle and critical-phase green splits are adjusted without changing the phase sequence, yellow time, or traffic-conflict relationships. Finally, the modified scheme is simulated again in SUMO to determine whether the comprehensive closeness and the main efficiency indicators have improved.

Because the study object is a continuous arterial corridor, large differences in cycle length among intersections make it difficult to coordinate vehicle arrival patterns. Therefore, the major signal controllers in the corridor are assigned a common coordinated cycle of  $C = 110$  s. The basic effective green time of each phase is allocated in proportion to the critical flow ratio:

$$y_h = \frac{q_h}{s_h} \quad (9)$$

$$g_h = \frac{y_h}{\sum_{h=1}^H y_h} (C - L) \quad (10)$$

where  $y_h$  is the critical flow ratio of the  $h$ -th critical lane group;  $q_h$  is the traffic demand of that lane group;  $s_h$  is the corresponding saturation flow rate;  $g_h$  is the effective green time assigned to the  $h$ -th critical phase;  $H$  is the total number of critical lane groups or phases participating in green-time allocation;  $C$  is the signal cycle; and  $L$  is the total lost time in one cycle. To ensure safety and implementability, the yellow transition interval remains fixed at 3 s and a minimum-green constraint is imposed. When the green time of one phase is increased, time must be reallocated from other phases within the same cycle so that cycle conservation is satisfied. Table 2.

**Table 2.** Signal cycles and optimized phase durations at major intersections.

| Intersection          | Original cycle / s | Optimized cycle / s | Optimized phase durations / s |
|-----------------------|--------------------|---------------------|-------------------------------|
| Jianshe Road          | 306                | 110                 | 36/3/18/3/27/3/17/3           |
| Wenhua Road           | 206                | 110                 | 40/3/15/3/28/3/15/3           |
| Longze Road           | 172                | 110                 | 16/3/17/3/12/3/33/3/17/3      |
| Dacheng Road          | 96                 | 110                 | 79/3/25/3                     |
| Hexi Road             | 96                 | 110                 | 79/3/25/3                     |
| East-side branch road | 134                | 110                 | 80/3/24/3                     |
| Binhe Road            | 110                | 110                 | 78/3/26/3                     |

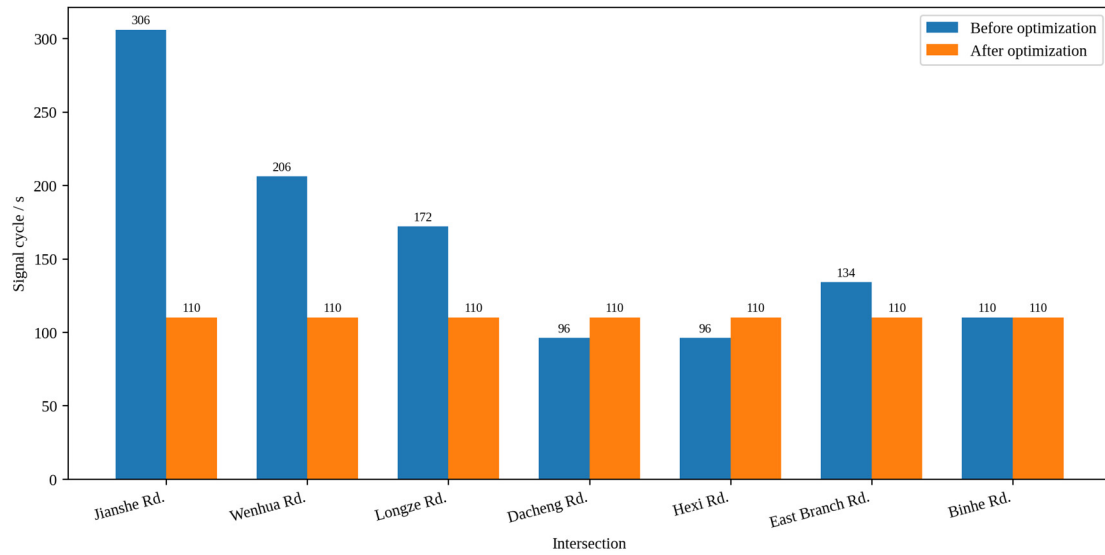


Fig 1. Comparison of signal cycles before and after optimization at each intersection.

## 4. Simulation Results and Analysis

### 4.1. Time-Efficiency Indicators

Table 3. Major traffic-performance indicators before and after signal timing optimization.

| Indicator                | Before optimization | After optimization | Improvement / % |
|--------------------------|---------------------|--------------------|-----------------|
| Average travel time / s  | 352.35              | 334.12             | 5.18            |
| Average waiting time / s | 240.12              | 220.31             | 8.25            |
| Average time loss / s    | 311.86              | 294.04             | 5.71            |
| Average queue length / m | 72.78               | 79.47              | -9.19           |
| Completed vehicles / veh | 2953.00             | 2918.00            | -1.19           |

The optimized scheme produces a clear improvement in vehicle time efficiency. The average travel time decreases from 352.35 s to 334.12 s, a reduction of 18.24 s and an improvement of 5.18%. The average waiting time decreases from 240.12 s to 220.31 s, a reduction of 19.80 s and an improvement of 8.25%. The average time loss decreases from

311.86 s to 294.04 s, corresponding to an improvement of 5.71%. Among these indicators, average waiting time exhibits the largest reduction, indicating that the common cycle and the reconstruction of the arterial green split improve vehicle travel mainly by reducing ineffective waiting caused by signal control.

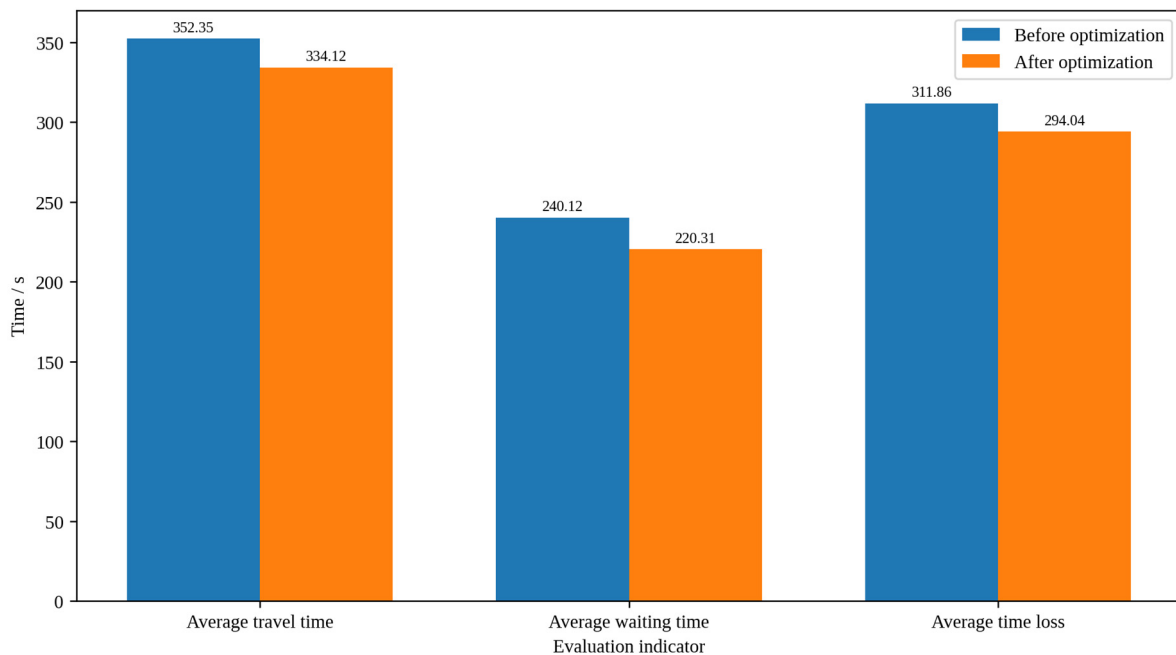


Fig 2. Comparison of time-efficiency indicators before and after signal timing optimization.

## 4.2. Queue Time-Series Characteristics

The time series of total network queue length shows a typical high-load operating pattern in both schemes: queues continue to grow during the demand-loading period and gradually dissipate after demand generation stops. The optimized scheme reduces the mainline queue during some periods, but its curve is not lower than the original scheme throughout the simulation. Correspondingly, the average

queue length increases from 72.78 m to 79.47 m, an increase of 9.19%. This result indicates that, after the common cycle is unified and green-time resources are redistributed, vehicle time costs decrease while queues are spatially transferred among different approaches and lanes. If average waiting time alone were used as the optimization objective, this spatial side effect could easily be overlooked; therefore, queue length needs to be included in the comprehensive evaluation.

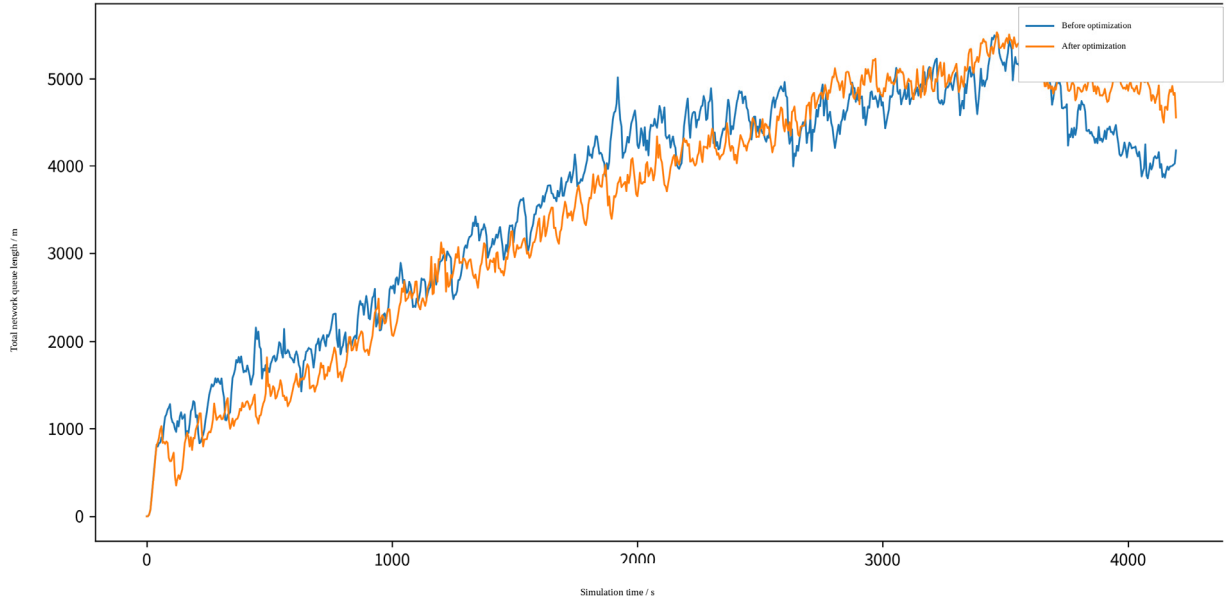


Fig 3. Time series of total network queue length before and after optimization

## 4.3. Traffic Flow Completion and Vehicle Throughput

The cumulative-arrival curves of the two schemes are generally close, showing that the optimization compares traffic demands of the same scale and that the improvement in time-related indicators is not achieved by reducing vehicle input. Within the unified evaluation window, 2953 vehicles are completed under the original scheme and 2918 vehicles

under the optimized scheme, a difference of approximately 1.19%. Although this difference is smaller than the improvement in the time-efficiency indicators, it also shows that the current optimized scheme has not yet achieved a simultaneous increase in throughput. For a continuous arterial, reducing vehicle delay and increasing the number of vehicles completed by the end of the simulation do not always occur simultaneously, particularly when end-of-simulation vehicle dissipation and local queue redistribution are present.

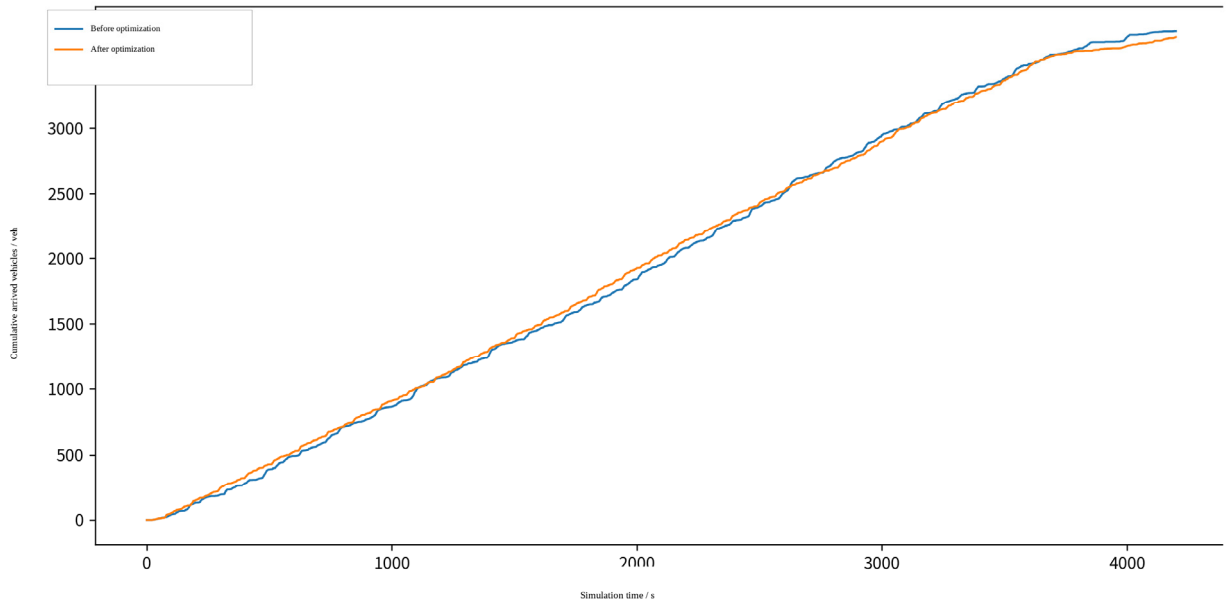


Fig 4. Time series of cumulative arrived vehicles before and after optimization.

#### 4.4. Entropy-Weighted TOPSIS Comprehensive Evaluation

**Table 4.** Entropy weights of evaluation indicators.

| Evaluation indicator | Entropy weight |
|----------------------|----------------|
| Average travel time  | 0.1318         |
| Average waiting time | 0.3457         |
| Average time loss    | 0.1616         |
| Average queue length | 0.3608         |

As shown in Table 4, average queue length and average waiting time receive relatively high weights of 0.3608 and 0.3457, respectively, while the weights of average time loss and average travel time are 0.1616 and 0.1318. The result

reflects the relatively pronounced differences in queueing and waiting indicators between the two schemes; therefore, the comprehensive evaluation cannot be determined by travel time alone. Table 5.

**Table 5.** TOPSIS evaluation results before and after optimization.

| Scheme              | TOPSIS relative closeness |
|---------------------|---------------------------|
| Before optimization | 0.4978                    |
| After optimization  | 0.5022                    |

The TOPSIS results show that the relative closeness of the original scheme is 0.4978, whereas that of the optimized scheme is 0.5022. Although the increase in the comprehensive score is modest, the optimized scheme still ranks ahead of the original scheme. Examination of the individual indicators shows that the optimization benefit

mainly originates from reductions in waiting time, travel time, and time loss, while the increase in queue length offsets part of the overall gain. This result demonstrates that entropy-weighted TOPSIS can not only rank alternative schemes but also reveal the trade-off between improved temporal efficiency and increased spatial queuing.

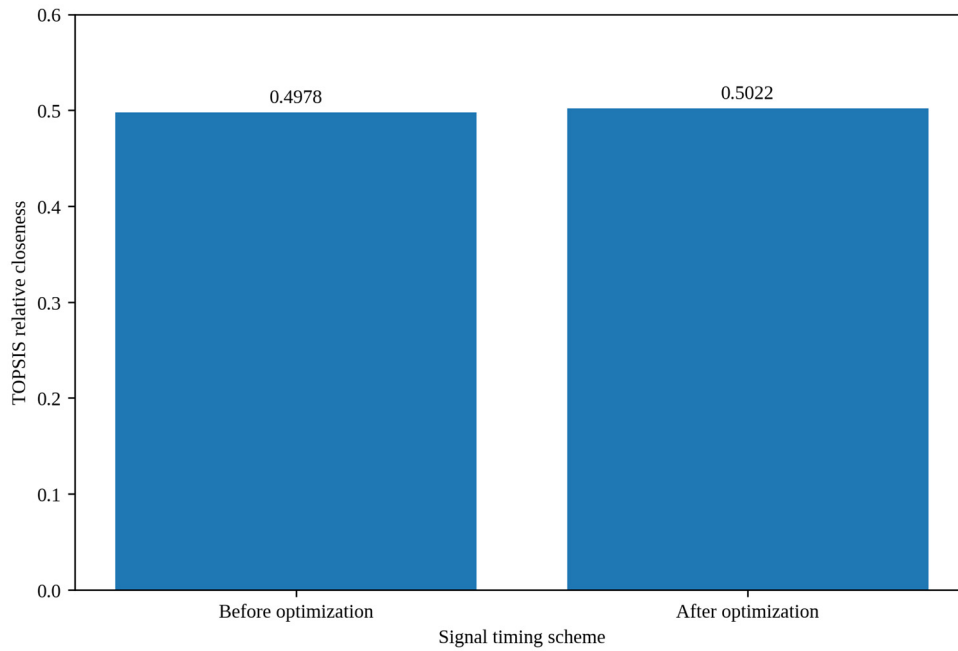


**Fig 5.** The TOPSIS results

## 5. Conclusion

(1) An evaluation-optimization process for urban arterial signal timing is developed. Based on a single SUMO simulation data chain, the process incorporates road-traffic operating indicators into an entropy-weighted TOPSIS evaluation and iterates the signal timing scheme through evaluation, diagnosis, adjustment, and re-evaluation.

(2) For the Beixin East Road corridor from Jianshe Road to Binhe Road, under a representative traffic demand of 59 OD pairs and 4470 veh/h, the coordinated cycle of the major intersections is unified to 110 s and the effective green time

of each phase is reconstructed according to critical flow ratios.

(3) SUMO results show that average travel time, average waiting time, and average time loss decrease by 5.18%, 8.25%, and 5.71%, respectively, after optimization, demonstrating that common-cycle coordination and green-split reconstruction can effectively reduce vehicle time costs.

(4) The average queue length increases by 9.19% after optimization, indicating that signal timing optimization changes the spatial distribution of queues among approaches. The entropy-weighted TOPSIS relative closeness increases from 0.4978 to 0.5022. The optimized scheme therefore ranks slightly above the original scheme overall, but spatial queuing

remains the principal constraint for subsequent optimization.

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