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A Study of Artificial Neural Network-Based Real-Time Traffic Signal Timing Design Model Utilizing Smart Intersection Data †

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Abstract: The smart intersection (SI) systems, as they are named in the Republic of Korea, are part of the ITS services implemented under local government projects with financial support from the central government. They collect real-time traffic data available at signalized intersections with advanced detection systems for surveillance purposes only. A traffic signal method utilizing such valuable data has been desirable but unavailable as yet in practice. This paper proposes a new approach to designing traffic signal timings, reflecting the demand changing in real time, by utilizing SI surveillance data. The proposed artificial neural network model generates suitable traffic signal timings trained to be near optimum based on surveillance data for each directional movement.

Keywords: traffic control; signal timings; deep learning; artificial intelligence; simulation; real time

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1. Introduction

The traffic signal timing design process in practice has focused only on a certain period of hours—namely, a.m. and p.m. peak times—due to insufficient budgets. Through the intelligent transport system (ITS) deployment projects in the Republic of Korea, local governments have guided the improvement of traffic control systems. Despite such investments, it has been hard to achieve the long-term goal as intended due to the failure of sustainability in online data collection. While practitioners want to believe their ITSs are 'advanced', it has been hard to keep reacting to the ordinary changes in traffic demand in real time.

The smart intersection (SI) systems being deployed through national projects have recently allowed traffic engineers to use sustainable online data obtained from various service components, such as traffic flow surveillance, incident detection, etc. Despite the availability of real-time surveillance data, the SI project has excluded traffic control services from its core functionality. Therefore, it might be preferable to link the traffic control systems and SI surveillance data. This paper delivers an approach to designing traffic signal timings by utilizing SI surveillance data, reflecting the demand changing in real time.

2. Related Work

For the SI systems, Kim et al. [1] suggested using image detection data to ensure the highest level of reliability, depending upon the Korean ITS performance evaluation criteria. They concluded that the data from their detection systems are sufficient to support the real-time design of traffic signal timings. Kim and Kim [2] proposed a new approach to test the 'Smart Traffic' signal operation method, including various operations such as emergency vehicle preemption. They employed the 'Verkehr In Stadten Simulation (VISSIM)' model to test them by utilizing real-time external data from outside of the simulation model; it was like a hardware-in-the-loop system. It was found that the traffic signal timings designed using online data performed better in real time than those using offline data, which is traditionally used for time-of-day (TOD) operation.

3. Model Development

This study aims to (1) train an artificial neural network (ANN) model designing traffic signal timings based on real-time SI surveillance data and to (2) compare its performance against one using traditional Time of Day (TOD) operation. It employed two different computer programs to overcome the unnecessary bias in simulations: corridor simulation (CORSIM) for the model development and simulation of urban mobility (SUMO) for the validation. It should be noted that a set of training data was from the hypothetical intersection operation scenarios and that the validation data were directly from the SI systems at the isolated 'Baekwoun' intersection, Uiwang, Gyeonggi, from November 2021 to November 2022.

For the ANN training data, 1470 (= 7 × 5 × 6 × 7) different traffic conditions were prepared to support the hypothetical intersection scenarios. The variation includes (1) seven different traffic demand levels, (2) five different free-flow speeds, (3) six different percent left turns, and (4) seven different approach balances, as shown in Table 1.

Table 1. Various traffic conditions scenarios for the ANN training data.

Total Volume Levels (≈v/c)	Free-Flow Speeds (km/h)	Percent Left Turns (%)	Approach Balances
0.95	40	5	0.50:0.50
0.92	45	10	0.55:0.45
0.88	50	15	0.60:0.40
0.85	55	20	0.65:0.35
0.75	60	25	0.70:0.30
0.65	-	30	0.75:0.25
0.55	-		0.80:0.20
No. of variations = 7	No. of variations = 5	No. of variations = 6	No. of variations = 7

To find the acceptable control conditions for these 1470 traffic conditions one by one, the authors developed a computer program, which they named CORSIM optimal signal timing (COST), to increase the training-data-preparation efficiency. Such control conditions were prepared based on the control-delay-minimization strategy. COST found the optimal control conditions for each of the traffic conditions through an iterative heuristic searching method, which is named the hybrid hill-climbing method, by utilizing the authentic CORSIM evaluation technique and automatically shifting to the next when found. The hybrid hill-climbing method employed in this study utilized sixteen combination cases of each of the conventional dual-ring phase representation schemes and changed its step size based on conditions designed to ensure the global optimum search.

The ANN model was then developed based on the training data reflecting 1470 different intersection operation scenarios—each having their own best control conditions and the traffic signal timing set. It was expected that the proposed ANN model could find either some similarity with the ones previously built or a hidden trend desirably leading to liquidity among such data.

The model development considered various compositions and combinations of ANN inputs, outputs, and hidden layers. The prepared input layer contained twelve input neurons, reflecting twelve directional movement volumes at a four-lag isolated intersection. The prepared output layer contained eight neurons, reflecting each of the conventional dual-ring phase lengths. The proposed model utilized a single hidden layer with sixteen units of neurons.

The ANN model was developed based on the training data reflecting 1470 different intersection operation scenarios. Figure 1 shows the architectural configuration that utilized the ANN model through actually operated Smart Intersection(S.I) data. The state was calculated through monitoring, which was input into the ANN model. The optimal signal time was calculated through the existing learning method, and the input traffic volume was added as learning data. Through this process, the ANN model becomes more robust and can react to various situational data.

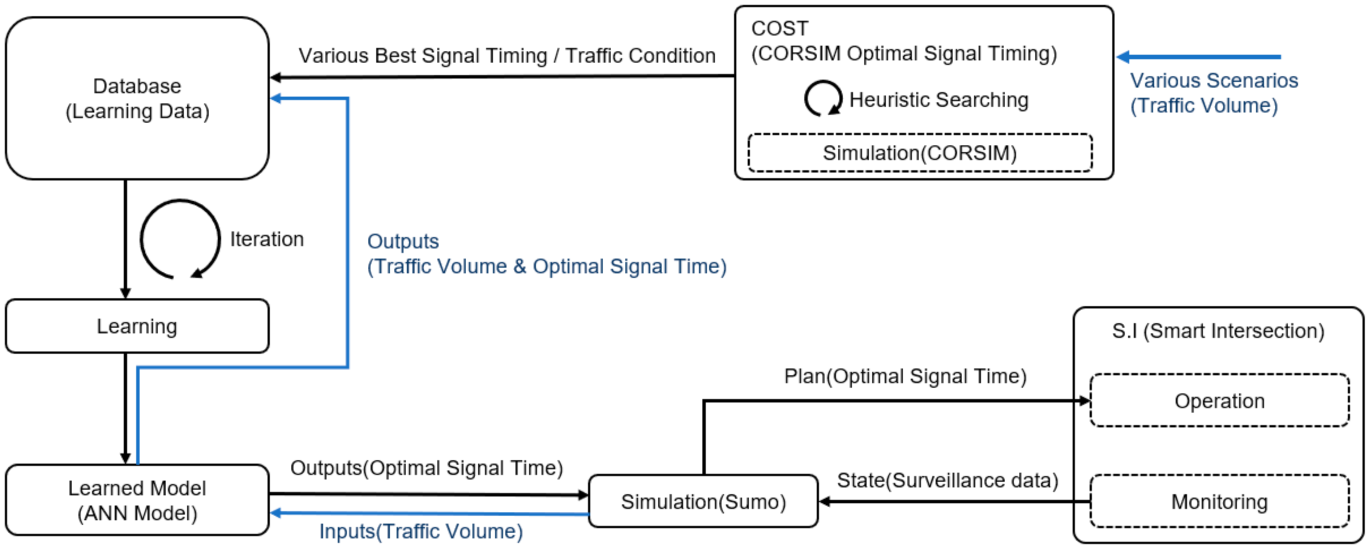

Figure 1. Study process.

4. Validation Test

To reflect the real-life demand variations in a day of twenty-four hours, the comparison test was done based on historical traffic volume counted for twenty-four hours on a weekday and a weekend from the SI surveillance systems. These data were obtained from the Uiwang SI traffic management center.

For the validation of the proposed ANN model, it was necessary to compare the performance of the isolated intersection with two different control conditions: the best-existing one in practice and the proposed hypothetical one utilizing SI surveillance data. The best-existing one was the TOD signal timings that have recently been updated in practice, whereas the proposed hypothetical one was from the ANN model developed in this study.

The authors employed weekday- and weekend-TOD signal timing plans updated through the official project of the Uiwang local government a month before this study. Table 2 presents a brief comparison of those control conditions in both TOD plans for weekday and weekend conditions.

Table 2. Existing/proposed signal operation method signal time setting.

TOD Classification	Existing		Proposed	
	Weekdays	Weekends	Weekdays	Weekends
00:00~06:00	TOD Plan 1	TOD Plan 5	The signal timings designed in real time with the proposed deep learning ANN model	
06:00~10:00	TOD Plan 2	TOD Plan 5		
10:00~17:00	TOD Plan 3	TOD Plan 8		
17:00~20:00	TOD Plan 4	TOD Plan 8		
20:00~21:00	TOD Plan 4	TOD Plan 5		
21:00~24:00	TOD Plan 1	TOD Plan 5		

The prepared traffic and control conditions were simulated with SUMO. Figure 2 illustrates the graphical comparison of the results. The horizontal axis represents the twenty-four hours of the day. The vertical axis represents the control delay estimated from the simulation.

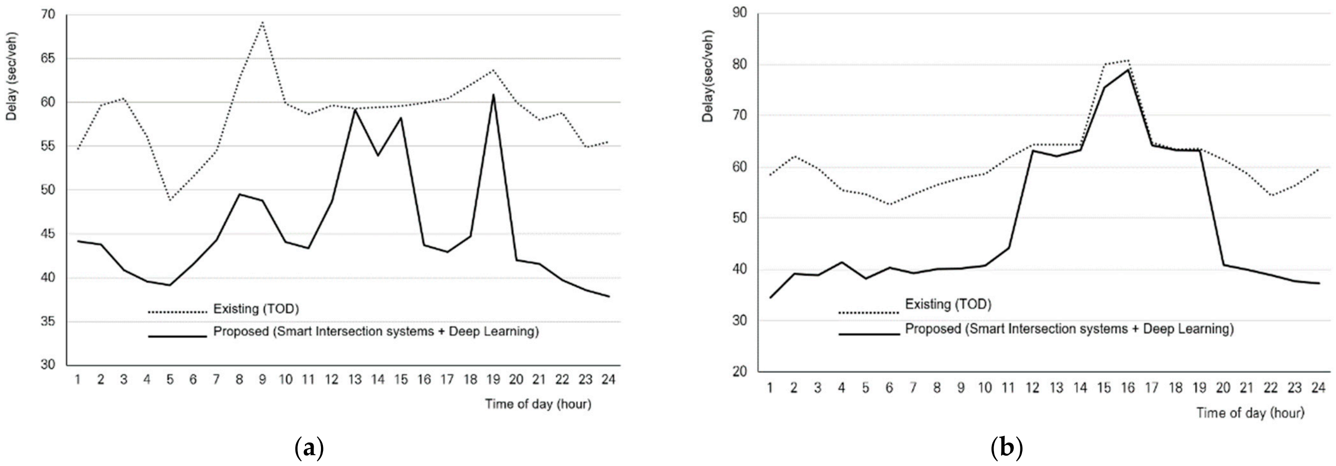

Figure 2. Comparison of existing vs. proposed control conditions for (**a**) weekdays and (**b**) weekends.

It was found from the results that the existing signal timing design method performed well during peak hours but not for the rest of the day. It showed that the basic traffic volume data utilized for traffic signal design and the invested resources, such as money and manpower in the signal timing design procedure, might be limited in practice as long as it is done in an offline manner.

The proposed model showed that during peak hours, the performance level was close to the TOD values. In addition, it was able to provide better performance during non-peak hours. It should be noted that the proportion of non-peak hours in a day is significant. This is because the proposed method uses online data and updates the signal timings in real time. Although it cannot be concluded from the results that the proposed ANN model produced the best signal timings, it can be concluded that the proposed approach utilizing the ANN technique was able to find a hidden trend.

5. Conclusions

This paper presents an approach to designing traffic signal timings based on online SI surveillance data, reflecting real-time changes in traffic demand. The authors suggest that it is valuable to link SI surveillance services with traffic signal control systems. The performance of the proposed optimal signal timings showed that the level of the control delay was reduced by about 22% on average compared with the existing method widely used in practice.

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