A Cycle Optimization Method for Multiple TSP Requests based on VISSIM-based GA

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Abstract — For the situation of multiple priority requests, the serve sequence is one of several key factors that have a significant impact on the efficiency of Transit Signal Priority (TSP) strategies. The serve sequence relates to the TSP parameter settings and the priority phase settings. Therefore, the TSP optimization for multiple priority requests should consider the different combinations of priority phase settings in TSP strategies. In order to achieve that objective, this paper presents a cycle optimization method for multiple TSP requests based on VISSIM-based GA. The optimization method uses the length of signal cycle as its optimization time interval. This can not only consider the vehicle arrivals before the priority requests, but can also consider the vehicle arrivals after the priority requests. The optimization method uses VISSIM-based GA to optimize the TSP timing on a single signal cycle with different combinations of priority phase settings. The optimization method uses the VISSIM-COM functions “Save Snapshot” and “Load Snapshot” to ensure the VISSIM-based GA optimization of each signal cycle starts with the same initial traffic state. The experiments result shows that the cycle optimization with different priority phase settings can significantly improve the precision of VISSIM-based GA optimization when the TSP strategy is effective for the simulation program. The impact of previous cycle optimization will be offset by the next cycle optimization which can also handle traffic fluctuations. The optimization results are generated by the combinations of cycle optimization, VISSIM-based GA, and priority phase settings.

Keywords - transit signal priority; multiple priority requests; viissim-based GA; cycle optimization; TSP strategy

I. INTRODUCTION

TSP is a control strategy that provides priority for transit vehicles from signal controllers at signalized intersections [1-3]. It is widely accepted as a viable solution to improve the reliability and service level for public transit systems [4]. For the situation of multiple priority requests, the serve sequence is one of several key factors that has a significant impact on the efficiency of TSP strategies. The conventional First-In-First-Service (FIFS) rule for multiple priority requests may affect the service of other transit vehicles and general vehicles. It often fails to offer an efficient solution to reduce the delay of transit vehicle, improve the schedule adherence of transit vehicles, and minimize the impact on general vehicles [5]. Therefore, the serve sequence for multiple priority requests should be considered in the process of TSP optimization.

The serve sequence relates to the TSP parameter settings and the priority phase settings. The models for multiple priority requests are grouped into two categories. The first category is for models having only one single priority phase. Most models for multiple priority requests belong to this category. The second category is for models having multiple priority phases. The models for conflicting priority requests belong to this category. Therefore, the TSP optimization for multiple priority requests should consider the different combinations of priority phase settings in TSP strategies.

The research that studies TSP optimization can be grouped into two categories. The first category is the optimization methods of analytical approaches. They are
usually built by mathematical models. The second category is the optimization methods of simulation-based intelligent algorithm. They are usually coupled with microscopic simulation and intelligent optimization algorithms.

A. Analytical Approaches

Mesbah et al. (2011) presents a bi-level optimization programming method that considers modal split, traffic assignment and transit assignment [7]. Zhang (2011) presents a TSP optimization model that integrates with US DOT IntelliDrive initiative functions. Ma and Ye (2013) presents an offline model that obtains an optimization solution for the signal cycle in the presence of bus priority. Ma et al. (2013) presents a person-capacity-based optimization method that integrates the design of lane markings, exclusive bus lanes, and passive bus priority signal settings for isolated intersections [8]. However, it is difficult to analytically optimize the TSP timing that is actuated by the random arrival of transit vehicles. The TSP setting is usually adjusted on the experience of traffic engineers. Moreover, the analytical optimization methods cannot model the complex driving behaviors (e.g., car following behavior, lane change, lateral behavior, signal control) and complex traffic scenarios (e.g., bus stops, special geometric forms of intersections). They need to customize the model for the specific traffic condition. This will restrict their application scope. Therefore, micro-simulation optimization is developed to optimize the timing of TSP systems as well as fully adaptive signal control systems.

B. Simulation-based Intelligent Algorithms

Stevanovic (2007) presents a VISSIM-based GA optimization method. It can optimize traffic signal timing both for transit vehicles and private vehicles. The results show that the timing plans optimized by VISSIM-based GA method outperformed the timing plans from the field and SYNCHRO. Zhou (2007) presents an adaptive TSP strategy that applies a parallel VISSIM-based GA to optimize adaptive traffic signal control with TSP. Ghanim (2009) presents a real-time TSP strategy that integrates a VISSIM-based GA model and an Artificial Neural Networks (ANN) model. Stevanovic (2011) applies a VISSIM-based GA optimization method to investigate the benefits of each optimization on a large urban traffic corridor. Bagherian (2014) presents a framework to optimize the location of TSP treatments. The framework applies a Binary Particle Swarm Optimization (BPSO) algorithm linked to a simulation-based model (VISSIM and SIDRA intersection software) to find the optimum solution throughout all possible combinations. The intelligent algorithm such as GA can efficiently search the best TSP timing. Therefore, the simulation-based intelligent algorithm is suitable for the TSP optimization with the situation of multiple priority requests.

From the analysis of existing TSP optimization methods, this paper presents a cycle optimization method for multiple priority requests based on VISSIM-based GA. The optimization method does not need to process each priority request as the analytical approaches. It considers the arrival of all transit vehicles and general vehicles in a suitable time interval to maximize the efficiency of transit vehicles and reduce the impact on general vehicles. The introduction of the optimization method is as follows:

1) All the vehicles that are waiting before the stop line will usually go through the intersection in one signal cycle. Therefore, the optimization method uses the length of signal cycle as its optimization time interval to improve the optimization precision. Additionally, the optimization method allows the control logic parameters of different TSP strategies to pass from one signal cycle to another signal cycle. With this setting, the optimization can not only consider vehicle arrivals before the priority requests, but can also consider vehicle arrivals after the priority requests.

2) The optimization method uses VISSIM-based GA to optimize the TSP timing on a single signal cycle. The optimization process considers the different combinations of priority phase settings in TSP strategies. This can improve the optimization precision for multiple priority requests.

3) The optimization method uses VISSIM as the evaluation environment for GA optimization. VISSIM is good at modeling public transit systems and TSP strategies.

4) The VISSIM-COM functions “Save Snapshot” and “Load Snapshot” can be used to save and load the traffic state. They allow the TSP optimization of each signal cycle to start with the same initial traffic state.

This paper presents the description of the TSP optimization method, analyzes the TSP control logic of Siemens 2070 and Hisense SC3080, and then designs the experiments to test the optimization method. The experiments’ result shows that the TSP optimization method can generate a precise TSP timing for multiple priority requests.

II. Method Descriptions

A. The Cycle Optimization Procedure based on VISSIM-based GA with Different Priority Phase Settings

1) According to the VISSIM-COM programming, the optimization procedure will return the length value of the signal cycle. Before running the VISSIM simulation, if it is needed, the optimization procedure will use the VISSIM-COM function “Load Snapshot” to load the traffic state of the last signal cycle. After running the VISSIM simulation in a signal cycle with the optimized timing, the optimization procedure will use the VISSIM-COM function “Save Snapshot” to save the traffic state. This can ensure the GA optimization of each signal cycle starts with the same initial traffic state (Figure 1).

2) The TSP timing optimization works best when the basic timing is optimized firstly. Therefore, basic timing and then TSP timing will be optimized by calling the genetic algorithm procedure (Figure 2).

3) The optimization procedure will choose optimization processes according to the arrival of transit vehicles in different signal phases. If the multiple priority requests are from different signal phases, the procedure will optimize the TSP timing with all the possible combinations of priority phase settings in TSP strategy. If the multiple priority requests are from a single signal phase, the procedure will...
optimize the TSP timing of the request priority phase in TSP strategy. If no priority request is received, the procedure only optimizes the basic timing.

4) The simulation test-bed will record the information of optimization process. The information contains the execution records of TSP strategy with different combinations of priority phase settings, basic timing records, TSP timing records, and the measures of effectiveness (MOEs) of simulation program.

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**Figure 1.** The cycle optimization based on VISSIM-based GA with different priority phase settings
B. The VISSIM-based GA Procedure

The VISSIM-based GA procedure will terminate a solution search if the maximum number of generations has been reached or if the population fitness meets the requirement of formula.

\[ \min \{ \text{fitness}_1, \ldots, \text{fitness}_n \} - \text{Average}\{ \text{fitness}_1, \ldots, \text{fitness}_n \} < \varepsilon \]  

Where (1) \( n \) is the total number of the signal timing population;

(2) \( \varepsilon \) is the value of the convergence threshold.

The procedure sets four steps to accelerate the convergence speed of VISSIM-based GA and keep the precision of GA searching (Figure 2).

1) Sets a high value of total population number;

2) Sets a suitable range of population values that considers the different numbers of binary digits to reduce the calculation amount;

3) Sets a suitable protection rate and elimination rate (the protection population will pass to the next generation directly);

4) Excluding the protected population, chooses from the remaining population those that have high weights (formula (2)) to compose a new sub-generation to execute the crossover and mutation process.

\[ \text{Weight}_i = \text{Int}[10000 \times \text{Square}(1/\text{fitness}_i)] \]  

Where, \( i \) is the number of the signal timing population.

C. TSP Strategies

Most simulation models usually lack some features and functions of the TSP models that are embedded in the real-world signal controllers (22). These oversimplified simulation models may generate some inconvincible conclusions and mislead the application (22). The optimization procedure uses VISSIM-COM programming to model the TSP strategies of Siemens 2070 and Hisense SC3080. For the cycle optimization, in the all-red time of last phase, the procedure will calculate the length of signal cycle and set the value of simulation period to be the length of signal cycle.

Siemens 2070

Figure 3 shows the TSP control logic for a Siemens 2070 signal controller. The priority phases execute the green extension strategy. The non-priority phases execute the early green strategy.

The expressions of “TSP requests” and “Get Final green time” are shown in Figure 4. The procedure uses VISSIM-COM Detector function “IMPULSE” to detect the arrival of transit vehicles. If the headway of bus arrival is smaller than the Max_call time, the Final green time of priority phase will add a Duration time. If the headway of bus arrival is between the Max_call time and the Extend time, the Final green time of priority phase will not add a Duration time. If the headway of bus arrival is larger than the Extend time, the procedure will accept the TSP requests again.

For the TSP phase settings (Figure 1), The TSP parameter passing is as follows (Figure 3):

1) Single priority phase. If the priority phase is not the first phase, the value of Early-green will be passed to the next signal cycle.

2) Multiple priority phases. If the priority phase is not the first phase, the Early-green value of this phase will be passed to the next signal cycle. When the green time of one priority phase is active, the procedure still processes the priority requests that are from the remaining priority phases. When the green time of non-priority phase is active, the procedure will process the all priority requests.

Additionally, during the amber time and all-red time of each phase, the settings are the same with during the green time of non-priority phase.

Hisense SC3080

The TSP strategy of Hisense SC3080 is a cycle balance strategy. It is suitable for the TSP implement under the condition of arterial coordinated control. Figure 5 shows the TSP control logic for Hisense SC3080 signal controller. The priority phases execute the green extension strategy. Only the last non-priority phase before the priority phases will execute the early green strategy. The green time of priority phase depends on the early green time of last non-priority phase.

For the TSP phase settings (Figure 1), The TSP parameter passing is as follows (Figure 5):

1) Single priority phase. If the priority phase is the first phase, the Early-green value and Green-extension value of this priority phase will be passed to the next signal cycle. If the priority phase is not the first phase, only the Early-green value of this priority phase will be passed to the next signal cycle.

2) Multiple priority phases. This situation is the same with the two settings of the situation of a single priority phase. The remaining settings are the same with the situation of multiple priority phases for Siemens 2070 signal controller.
Maximum number of generations
Total number of population
Population values of first generation
Protection rate of population
Elimination rate of population
Crossover rate of population
Mutation rate of population
Convergence threshold

Start

Initialization

Run VISSIM simulation in a signal cycle

Return the fitness and cycle length

Current number of population = total number of population

Sort the fitness from small to large record Min(fitness[i]) and average(fitness[i])

| Min(fitness[i]) - average(fitness[i]) |
|< convergence threshold

Yes

Generate new generation

Current number of generation < maximum number of generation

Yes

Choose the protection population

Replace the elimination population by the rest population

Calculate the weights of rest population
weights[i] = Int[10000*square (1/fitness[i])]

Choose the remaining population according the weights[i] of rest population

Encode to binary format

Execute population crossover

Execute population mutation

Encode to decimal format

Generate new generation with protection population and new population

No

Yes

Break the calculation

Return the best population

End

Choose the protection population

Replace the elimination population by the rest population

Calculate the weights of rest population
weights[i] = Int[10000*square (1/fitness[i])]

Choose the remaining population according the weights[i] of rest population

Encode to binary format

Execute population crossover

Execute population mutation

Encode to decimal format

Generate new generation with protection population and new population

No

Yes

Yes

Yes

No
Figure 3. The TSP control logic for Siemens 2070 signal controller
III. EXPERIMENT DESIGN

A. VISSIM Program Setting

1) Simulation intersection

The name of simulation intersection is Chaoyang-Gaobeidianbeithat is located in Beijing. Figure 6 illustrates the background map of the simulation intersection. The virtual bus detectors were placed 52 and 65 meters upstream of the bus stop lines respectively.

2) Traffic demand

Traffic data was collected from 5pm to 7 pm on Nov 12 2013. The traffic volume is counted during the length of the signal cycle (193 seconds). The vehicle composition is mainly composed of general vehicles, regular buses, BRT vehicles and pedestrians. The labels of origin and destination (OD) zones are shown in Table 1. In column “Transit vehicles”, the sub columns “O1-D1 (1)” and “O1-D6 (1)” relate to the regular buses which pass the intersection without stopping at bus stops; the sub columns “O1-D1 (2)” and “O1-D6 (2)” relate to the regular buses which pass the intersection with stopping at the bus stops; the sub columns “O2-D2” and “O4-D4” relate to the BRT vehicles. Additionally, the total volume of pedestrians was 1600 ped/h.
Figure 5. The TSP control logic for HisenseSC3080 signal controller
B. Genetic Algorithm Setting

There are two optimization processes needed in the GA. One is the basic signal timing optimization. The other is TSP signal timing optimization (Figure 1). The GA uses personal delay (the average delay per person that can be acquired from VISSIM simulation) as its fitness. The findings show that personal delay represents a suitable objective function for the TSP optimization to minimize the negative impact to the entire intersection (2, 4, 12).

The values of GA parameters are as follows: the maximum number of generations is 50; the total number of population is 30; the protection number of population is 6; the elimination number of population is 3; the crossover number of population is 12; the mutation number of population is 3; the convergence threshold is 1(formula (1));

C. Experiment Plan

To test the effect of optimization method that is presented by this paper, four experiments were conducted as follows:

1) Experiment 1

Experiment 1 was conducted with the effect of initial basic timing that is from the field investigation. It was used as a comparison group. The signal phase sequences are

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Figure 6. The background map of the simulation intersection
shown in Figure 6. For the initial basic timing, the green time of first phase is 64 seconds; the green time of second phase is 30 seconds; the green time of third phase is 52 seconds; the green time of fourth phase is 23 seconds. Additionally, the value of amber time of all experiments is 4 seconds; the value of all-red time of all experiments is 2 seconds.

2) Experiment 2

Experiment 2 was conducted to test the effect of empirical TSP timing without optimization. It was used as a comparison group.

The empirical TSP timing for Siemens 2070 in this simulation program is as follows: the maximum green time of first phase is 84 seconds; the minimum green time of first phase is 64 seconds; the maximum green time of second phase is 30 seconds; the minimum green time of second phase is 20 seconds; the maximum green time of third phase is 52 seconds; the minimum green time of third phase is 42 seconds; the maximum green time of fourth phase is 23 seconds; the minimum green time of fourth phase is 23 seconds; the Max_call time is 3 seconds; the Extend time is 7 seconds; the Duration time is 10 seconds (Figure 4).

The empirical TSP timing for Hisense SC3080 in this simulation program is as follows: the green times of four phases are the same with the experiment 1; the maximum early green time is 5 seconds (Figure 5).

3) Experiment 3

Experiment 3 was conducted to test the effect of hour optimization (a possible TSP timing will run an hour to generate the fitness value) based on VISSIM-based GA. Experiment 3 set the first phase as the priority phase. It was used as a comparison group. The optimization procedure is shown in Figure 2. The parameters needed to optimize are the same with experiment 2.

4) Experiment 4

Experiment 4 was conducted to test the effect of cycle optimization (a possible TSP timing will run a signal cycle to generate the fitness value) based on VISSIM-based GA with different priority phase settings. Each TSP strategy has three priority phase settings (Figure 1). The first phase and the third phase are chosen to compose the three priority phase settings. The parameters needed to optimize are the same with experiment 2.

IV. SIMULATION RESULTS

A. Personal Delay

Figure 7 shows the personal delay of Siemens 2070. For the figure, the personal delay of empirical TSP timing without optimization has significantly decreased than the initial basic timing. This shows that the TSP strategy of Siemens 2070 is suitable for this simulation program. The personal delay of cycle optimization with different priority phase settings changing TSP timing each cycle of the hour is smaller than an hour optimization with the single best fixed TSP timing throughout the hour. The cycle optimization makes the personal delay to change more smoothly than other comparison groups from one cycle to another cycle. The impact of previous cycle optimization will be offset by the next cycle optimization which can handle traffic fluctuations. It is a result of the combinations of cycle optimization, VISSIM-based GA, and priority phase settings that work together.

Figure 7. The personal delay of Siemens 2070

Figure 8 shows the personal delay of Hisense SC3080. For the figure, the personal delay of empirical TSP timing without optimization has no significantly decreased than the initial basic timing. This shows that the TSP strategy of Hisense SC3080 is not suitable for this simulation program.

The personal delay of cycle optimization with different priority phase settings has no significantly decreased than hour optimization. Additionally, the personal delay of Hisense SC3080 has the similar changed trend with Siemens 2070 in cycle optimization.
Figure 8. The personal delay of Hisense SC3080

Table 2 shows the personal delay that is calculated in an hour. The personal delay of cycle optimization with different priority phase settings is smaller than hour optimization for Siemens 2070. It decreases 4.9 percent than hour optimization for this simulation program. This illustrates that the optimization method that is presented by this paper can fit traffic fluctuations to improve the precision of VISSIM-based GA optimization.

The personal delay of empirical TSP timing without optimization for Siemens 2070 has significantly decreased than Hisense SC3080. When comparing to hour optimization, the personal delay of cycle optimization with different priority phase settings has the similar situation. This shows that the TSP strategy of Siemens 2070 is more suitable than Hisense SC3080 for this simulation program. Therefore, the cycle optimization with different priority phase settings works best when the TSP strategy is effective for the simulation program.

Additionally, the personal delay of hour optimization for Siemens 2070 is close to Hisense SC3080. This illustrates that the TSP timing optimization after basic timing optimization (Figure 2) has the ability to search a better TSP timing for different TSP strategies. It can minimize the adverse impact of TSP strategies.

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<th>TSP strategy</th>
<th>Priority phase setting</th>
<th>Value(s)</th>
<th>Ratio(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Siemens 2070</td>
<td>The initial basic timing</td>
<td>129.6</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>The empirical TSP timing without optimization</td>
<td>106.9</td>
<td>17.5</td>
</tr>
<tr>
<td></td>
<td>The hour optimization based on VISSIM-based GA optimization</td>
<td>93.9</td>
<td>27.5</td>
</tr>
<tr>
<td></td>
<td>The cycle optimization based on VISSIM-based GA with different priority phase settings</td>
<td>87.6</td>
<td>32.4</td>
</tr>
<tr>
<td>Hisense SC3080</td>
<td>The initial basic timing</td>
<td>129.8</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>The empirical TSP timing without optimization</td>
<td>126.0</td>
<td>2.9</td>
</tr>
<tr>
<td></td>
<td>The hour optimization based on VISSIM-based GA optimization</td>
<td>94.8</td>
<td>26.7</td>
</tr>
<tr>
<td></td>
<td>The cycle optimization based on VISSIM-based GA with different priority phase settings</td>
<td>92.6</td>
<td>28.7</td>
</tr>
</tbody>
</table>

B. The Choices of Priority Phase Settings

Table 3 shows the choices of priority phase settings for the cycle optimization of VISSIM-based GA. From the table, there is no remarkable regularity both for Siemens 2070 and Hisense SC3080. This shows that the optimization results are generated by the combinations of cycle optimization, VISSIM-based GA, and priority phase settings that work together.
This paper presents a cycle optimization method based on VISSIM-based GA with different priority phase settings for multiple TSP requests. The primary conclusions of the optimization framework are:

1) For this simulation program, the cycle optimization with different priority phase settings of Siemens 2070 decreases 4.9 percent than hour optimization in personal delay. This illustrates that the optimization method can significantly improve the precision of VISSIM-based GA optimization.

2) The cycle optimization with different priority phase settings works best when the TSP strategy is effective for the simulation program.

3) The TSP timing optimization after basic timing optimization has the ability to minimize the adverse impact of TSP strategies.

4) The cycle optimization makes the personal delay to change more smoothly from one cycle to another cycle. The impact of previous cycle optimization will be offset by the next cycle optimization which can handle traffic fluctuations.

5) The optimization results are generated by the combinations of cycle optimization, VISSIM-based GA, and priority phase settings that work together.

The optimization method can be implemented in a better computer with several VISSIM interface running at the same time to meet the real-time requirement. The custom TSP strategies can be updated to signal controllers (Siemens 2070 and Hisense SC3080) by the NCTIP protocol[22]. In future work, the optimization method should be considered to test the situation of multiple custom TSP strategies with different combinations of priority phase settings. Additionally, the optimization method should be considered to use a multi-objective function (7, 18) to increase the differentiation degree of experiments results. The optimization method should be considered to test in the coordinated networks with the aim of schedule adherence.

### TABLE III THE CHOICES OF PRIORITY PHASE SETTINGS

<table>
<thead>
<tr>
<th>TSP strategy</th>
<th>The number of signal cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Siemens 2070</td>
<td>2 1 3 1 1 1 1 1 2 1 1 1 1 2 2 1 1 1 1 1</td>
</tr>
<tr>
<td>Hisense SC3080</td>
<td>1 1 2 1 3 1 2 1 2 2 1 2 2 2 2 3 3 1 1</td>
</tr>
</tbody>
</table>

### V. CONCLUSIONS

This work was supported in part by the program of National Key Technology R&D Program of China (No. 2014BAG03B03), the program of Beijing Municipal Commission of Science and Technology (No. K200411201302), and China Scholarship Council (CSC NO. 201406540019).

### REFERENCES


Author Contributions

Peikun Lian had conceived the study and drafted the paper. Zhenlong Li, Jian Rong, and Yuanwen Lai had revised this manuscript. Jack Keel contributed to the programming and writing.

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