Data Analysis with Multi-objective Optimization Algorithm: a Study in Smart Traffic Signal System

Pengzhe Zhou[#], Zhiyi Fang[#], Hongliang Dong[*1], Jiayue Liu[#], Shuaining Pan[#]

[#]*College of Computer Science and Technology, Jilin University*
No.2699 Qianjin Street, Changchun City, China

[*]*Information and Data Research Lab, Banine Technologies Ltd*
No.199 Pangu Sourth Street, Changchun City, China

[1]donghongliang@baninetech.com

Abstract**—Traffic optimization is an emerging area in the recent few years, with the rapid development of data analysis studies and techniques. Intersection is the hub of road traffic and play a vital role in alleviating the pressure on road traffic. Therefore, this study was done to improve indexes of traffic control and ease road congestion, in order to refine the traffic situation of the interaction.**

In this paper, traffic signal timing of individual interactions will be discussed. After an analysis and comparison of various road indexes, a signal timing algorithm based on multi-objective optimization was developed. The algorithm aims to reduce vehicle delay time, reduce the number of stops and improve the traffic capacity. It is applied by dimensionally processing the indexes, building a multi-objective optimization model and then adopting the fixed-step search method to program and determine the optimal signal cycle scheme for the current road condition and eventually allocating the time of green clearance for each phase according to the principle of equal saturation.

A real intersection was selected for this research. The specific data about this intersection was collected and used to launch experimental verification of the algorithm developed in this paper. Moreover, the optimization level of each phase and the current signal timing scheme for the interaction were compared.

Keywords**—data analysis, multi-objective, traffic optimization, smart traffic signal.**

I. Introduction

With the rapid development of China's economy, the urban population has expanded constantly, and the amount of traffic has constantly increased. However, road resources are limited, so roads in some large and medium-sized cities have been overloaded. As a result, serious road congestion, traffic chaos and other issues have occurred, so it is quite urgent to improve the road service capacity and achieve the scientific management of road conditions. In recent years, the government has also attempted to find a breakthrough for easing the pressure on urban road traffic, and promulgated a number of related policies. After the "intelligent traffic" concept was put forward, some large first-tier cities have made appropriate adjustments according to their own road conditions, so that their traffic situation has been significantly improved.

The traditional signal uses the time-lapse timing scheme to divide a day into several periods and set a cyclic timing scheme for each period. Once set, the scheme would never change. Obviously, such timing scheme is poorly-adapted, so it is impossible to take appropriate measures to deal with random variation in the traffic flow. And this scheme would easily cause unbalanced distribution of road resources. When setting the signal cycle scheme, some cities just focus on the improvement of some indexes, but ignore the fall of other indexes. Therefore, the signal timing scheme has a large room for improvement. In this paper, the traffic signal system in the intersection is based to improve and optimize the signal timing scheme.

II. Research at Home and Abroad

The idea of signal timing was first proposed in the England in the 19th century. However, scholars did not begin to study the signal timing, till the end of the Second World War. The well-known Webster timing was proposed by Webster and Miller. This timing algorithm is designed to reduce the vehicle delay time and optimize the signal cycle. This algorithm provides the basis for research on the signal timing algorithm. In 1975, the Transport and Road Research Laboratory of the UK used the green signal ratio-cycle length-phase difference optimization technology to successfully develop the SCOOT system. After that, on the basis of the Webster algorithm, Gazis studied a simple traffic network with 2 intersections. In 1992, Foy and other scholars developed a genetic algorithm for allocating and optimizing the green clearance time.

China made a late start in the intelligent transport business. However, in recent years, intelligent transport has developed rapidly in China. The "intelligent transport" concept was put forward in China. Moreover, some large cities have independently developed traffic timing schemes suitable for their local road conditions.

In recent years, some domestic scholars have conducted a lot of research on signal timing algorithms and achieved good results. In 1992, Xu Dongling and other scholars added fuzzy neural network to the intelligent algorithm and put forward a signal optimization timing algorithm for single-point intersections. In 1998, Gu Huaizhong [1] proposed a multi-objective joint optimization model of the delay time, traffic capacity and the number of parking times, and used the simulated annealing global optimization algorithm to solve the model. In 2007, Nan Chunli [2] replaced the traffic capacity in the multi-objective model with the vehicle density and adopted the linear weighted summation and the ideal point method. In 2008, Zhang Peng and other scholars put forward a joint

978-1-5090-5756-6/17/$31.00 ©2017 IEEE
SERA 2017, June 7-9, 2017, London, UK

optimization functions for the delay and traffic capacity, applied the triggering model and used the traversing search algorithm. In 2011, Zhou Li [3] proposed a signal control model based on dynamic time division, selected the delay and traffic capacity as parameters, introduced the robust control idea into the delay model and applied the improved NSGA-II for solution. In 2014, Zhang Lingxuan [4] and other scholars used Akcelik's delay formula, added the average delay time of pedestrian crossing to the model, and used the genetic algorithm for solution. Feng Shengli [5] proposed an optimal timing algorithm based on the Lagrangian multiplier method and applied the algorithm to the traffic situation with multi-phase sequences.

III. MULTI-OBJECTIVE OPTIMIZATION ALGORITHM WITH COMBINED STRATEGY

As indicated, the idea of multi-objective optimization is intended to achieve an optimized state of balance in problems involving more than one objective. In this state, multiple targets can be optimized simultaneously. However, the balanced state is difficult to reach in practice. Usually, the improvement of some targeted indexes is at the cost of other ones, but the costs are ignored regarding the general optimization. Therefore, the algorithm in this essay aims to apply the idea of multi-objective optimization to practical problems of transportation.

Indicators to measure the performance of road include 'road capacity', 'time of vehicle delay', 'number of vehicle stops', 'length of waiting lines' and so on. In this essay, the algorithm obtains multi-objective optimization through the simultaneous improvement of road capacity, average delay time and the number of vehicle stops.

A. Average time of vehicle delay

Reducing the time of vehicle delay can expand road resources, and increase the transport efficiency. Therefore, it is an important performance index of road services. The algorithm will use the equation proposed by Webster to calculate the average time of vehicle delay as shown below:

$$d_i = \frac{C(1-\lambda_i)^2}{2(1-\lambda_i x_i)} + \frac{x_i^2}{2q_i(1-x_i)} - 0.65\left(\frac{C}{q_i^2}\right)^{\frac{1}{3}} x_i^{(2+5\lambda_i)}$$

In the formula:

d_i — The average delay time of the i-th phase vehicle;

C — Signal cycle;

λ_i — The Green Time Ratio of the i-th phase;

x_i — The saturation of the i-th phase;

q_i — The actual traffic flow of the i-th phase.

After finding the average delay time of each phase, the average delay time of all phases of the intersection can be obtained, as shown below:

$$D = \frac{\sum_i^n d_i q_i}{\sum_i^n q_i} = \frac{\sum_i^n \frac{C\left(1 - \frac{y_i(C-L)}{YC}\right)^2}{2(1-y_i)} q_i}{\sum_i^n q_i}$$

In the formula:

D — The average delay time.

B. Number of stops

The number of stops is also an indicator of this article to be optimized, its formula is as follows:

$$h_i = 0.9 \times \frac{C(1-\lambda_i)}{1-y_i}$$

In the formula:

h_i — The average number of stops of the i-th phase

The average number of stops at the intersection is as follows:

$$H = \frac{\sum_i^n h_i q_i}{\sum_i^n q_i}$$

In the formula:

H — The average number of stops at the intersection.

C. Traffic capacity

In Multi-objective optimization algorithm, the traffic capacity of the intersection, which we want to optimize, its formula is as follow:

$$Q_i = S_i\lambda_i = S_i \frac{y_i(C-L)}{CY}$$

In the formula:

Q_i — The traffic capacity of the i-th phase;

S_i — The saturated flow of the i-th phase.

The total traffic capacity of the intersection is as follows:

$$Q = \sum_i^n Q_i$$

In the formula:

Q — The total traffic capacity of the intersection.

The purpose of the algorithm is to improve the capacity, reduce the average delay time and the number of parking times. Therefore, this paper constructs the multi-objective optimization model as follows:

$$\min F = \frac{k_1 \frac{D}{D_0} + k_2 \frac{H}{H_0}}{k_3 \frac{Q}{Q_0}}$$

In the formula:

k_1 — The weighting factor of average vehicle delay;

D — The average delay time for vehicles;

D_0 — The average delay time of the initial vehicle;

k_2 — The weighting factor of the average number of stops;

H — The average number of stops at the intersection;

H_0 — The initial average number of stops;

k_3 — The weighting factor of traffic capacity;

Q — The traffic capacity of Intersection;

Q_0 — The initial traffic capacity of Intersection.

In the model, I use the delay time and the number of stops as a numerator, taking the capacity as a denominator. The parameters are dimensionally processed, because of the three indicators of the different unit.

After the parameters are dimensionally processed, according to the actual situation to determine the impact of each parameter on the value of function F, and assign values to k_1, k_2, k_3, so this article will take the following values for the coefficients:

$$k_1 = C\frac{1 - Y}{1800}$$
$$k_2 = (1 - Y)y_i$$
$$k_3 = CY$$

In order to ensure traffic safety, and taking into account the actual situation at the intersection, the constraints of the model are as follows:

$$\text{s.t.}\begin{cases} ge_{min} \le ge_i \le ge_{max} \\ C_{min} \le C \le C_{max} \\ 0.6 \le x \le 0.9 \end{cases}$$

At this point, the multi-objective optimization model is established.

According to the model, it can be seen that the period when the minimum value of F is the best period for the current traffic flow. Therefore, solving this model becomes minimizing function F after using these three indexes in it and transforming the rest variables into variables that have period C and combination of known variables.

IV. ANALYSIS OF EXAMPLES

In this experiment, the data set was captured from actual traffic flow in one of the intersectional junction, on the urban road. We measured the distribution of the traffic flow for this cross during rush hours (7:00 – 9:00) in the form of traffic flow per hour as shown in the following Table 1 and Table 2:

TABLE I

THE AVERAGE TRAFFIC PER HOUR AT THE INTERSECTISS

Average traffic per time period	**Entrance**				
	East Entrance				**North Entrance**
	Left	Straight 1	Straight 2	Straight and Right	Left Straight and Right
Traffic per lane	198	497	457	440	111
Total	198	1394			111

TABLE II

THE AVERAGE TRAFFIC PER HOUR AT THE INTERSECTION

Average traffic per time period	**Entrance**			
	West Entrance		**South Entrance**	
	Left	Straight and Right	Straight and Left	Straight and Right
Traffic per lane	6	580	304	186
Total	6	580	490	

After optimization, we compare all the indexes for timing design algorithm as shown in the following Table 3 and Table 4:

TABLE III

TABLE OF INDEXES OF TIMING DESIGN ALGORITHM

Timing method	**Period**	**Green time/Green time ratio**		
		First Phase	**Second Phase**	**Third Phase**
Research status	114	57/0.5	23/0.2	25/0.22
Webster timing	72	37/0.47	14/0.19	15/0.21
Multi-objective optimization	152	80/0.53	29/0.19	34/0.22

TABLE IV

TABLE OF INDEXES OF TIMING DESIGN ALGORITHM

Timing method	**Average delay time**	**Average number of stops**	**Total Traffic capacity**
Research status	29	85	4901
Webster timing	20	57	4448
Multi-objective optimization	36	109	5096

It can be seen from the data in the tables that the periodicity calculated by the Webster method is smaller than that of the existing time-design scheme at the intersection, and the green ratio of each phase is slightly lower. However, the average delay time of the vehicle is reduced by 31%, the number of stops decreased by 33%, the capacity decreased by 452pcu / h. So the Webster method is suitable for traffic flow smaller case and in the case of large traffic flow effect is not good. In this paper, the multi-objective optimization method, the capacity is improved by 195pcu / h, the other two indicators decreased slightly.

This is because the intersection of the current traffic flow is large and multi-objective algorithm at this time pay more attention to enhance the traffic capacity of the intersection. Then the delay time and the number of parking times are placed in the secondary position. It can be seen that the multi-target timing algorithm has greatly improved the traffic capacity of the intersection. We don't calculate the normal hour indexes because they can be calculated in same way as rush hours.

V. SUMMARY AND OUTLOOK

At present, the optimization method of intersectional signal is unitary, which normally focus on the enhancement of a single performance index. Different from the current approach, the algorithm in this essay optimizes the index of road capacity, average delay time as well as the number of vehicle stops, and focus on the enhancement of the level of intersection services. Compared with the traditional method of timing control, this algorithm adjusts the traffic signal timing scheme of interactions dynamically according to traffic flows on roads, thus responding to the change of traffic flows better.

REFERENCES

[1] Gu Huaizhong Wang Wei. "A Global Optimization Simulated Annealing Algorithm for Intersection Signal Timing"(Research Institute of Transportation Engineering, Southeast University, Nanjing 210096), 68-72, 1998(3).

[2] Nan Chunli, "Multi-object Traffic Organization and Optimization Modeling and Simulating Based on AOP at Signalized Intersection". Chang'an University, 2007.

[3] Zhou Li. "Study on Signal Control Model and Algorithm at Isolated Intersection Based on Dynamic Time-of-Day". Shandong University. 2011.

[4] Duan Jinglin, "Research on Dynamic Timing Optimization Algorithm for Urban Traffic Lights". Shenyang University, 2014.

[5] Feng Shengli, "The Research on Signal Timing Optimization of Isolated Intersection Based on Multiphase and Variable Phase Sequence", Lanzhou Jiaotong University,2014.