An International Journal of Optimization
and Control: Theories & Applications
Vol.3, No.1, pp.35-43 (2013) © IJOCTA
ISSN: 2146-0957 eISSN: 2146-5703
DOI: 10.11121/ijocta.01.2013.00138
http://www.ijocta.com

Genetic algorithm for optimization in adaptive bus signal priority control

Tran Vu Tu [a] and Kazushi Sano [b]

[a] Department of Civil Environmental Engineering, Nagaoka University of Technology,
Kamitomioka, 1603-1, Nagaoka, Niigata, 940-2188, Japan
Email: trvutu@stn.nagaokaut.ac.jp

[b] Department of Civil Environmental Engineering, Nagaoka University of Technology,
Kamitomioka, 1603-1, Nagaoka, Niigata, 940-2188, Japan
Email: sano@nagaokaut.ac.jp

(*Received September 18, 2012; in final form November 22, 2012*)

Abstract. This paper firstly proposes an improved genetic algorithm (GA) for optimization in adaptive bus signal priority control at signalized intersections. Unlike conventional genetic algorithms with slow convergence speed, this algorithm can increase the convergence speed by utilizing the compensation rule between consecutive signal cycles to narrow new possible generated population spaces. Secondly, the paper would like to present a way to apply the algorithm to a simple adaptive bus signal priority control as well as compare how much the computation time is saved when applying the improved algorithm. Then the research thirdly investigates the efficiency of the proposed algorithm under various flow rate situations. The results show that the improved genetic algorithm can reduce the computation time considerably, by up to 48.39% for the studied case. With high saturation degrees on the cross street, the convergence rate performance of the improved genetic algorithm is significantly good. The figure can be up to 36.2% when compared with the convergence rate of the conventional GA.

Keywords: Optimization; signal control; genetic algorithm; priority.
AMS Classification: 90C11

1. Introduction

Genetic algorithms are global optimizers that have been used succesfully for many research studies [2], [3], [12], [20]. Compared with other traditional optimization techniques such as random search, gradient methods, iterated search, simulated annuealing, etc., the genetic algorithm can overcome the shortcomings that the other methods incur. In addition, these traditional optimization techniques lack both speed and robustness needed for real-time adaptive traffic signal control [7]. Therefore, genetic algorithms should be the suitable way for complicated signal control optimizations.

Indeed, traditional optimization techniques remain important limitations. Specifically, the random search optimization technique is considered as a very unintelligent strategy because of the random selection in the search space [2]. Some other optimization techniques using the guide of direction of search called gradient methods can improve the computation convergence speed well. However, these methods usually fail because of the discontinuity that causes the impossibility of the function-derivative computation. By combining random search and gradient search, the iterated search technique is also considered a good way of optimization problems. Although this combination can improve the speed significantly, no overall picture of the "shape" domain is obtained because each random trial is carried out

Corresponding Author. Email: trvutu@stn.nagaokaut.ac.jp

in isolation. Similarly, a modified version of hill climbing method called simulated annuealing technique was developed to be a good way for optimization. But, this method only deals with one candidate solution at a time and therefore does not build up an overall picture of the search space [2].

In bus signal priority control, minimizing negative effects on traffic to find proper sets of parameters has been objectives of many research studies [14], [23]. The scope of the optimizations covered not only isolated signalized intersections, arterial roads with multi-intersections but also large traffic networks with co-ordinations among signalized intersections. The larger the scope is, the more complicated the optimization problems are. Especially, the complexity becomes problematic when a lot of realated factors such as signal state, pedestrian factor, traffic factor are concerned in adaptive bus signal priority control. Therefore, to optimize such a multi-dimension problem, GAs have been chosen as the proper way [1], [8], [10], [13]. But, most of these papers focused on developing methods to apply GAs as a way to optimize only. The slow convergence speed of conventional GAs has not received much attention. The huge computation time of conventional GAs is a obstacle to any real-time application. Several advances in the field of evolutionary computation have been suggested to overcome the obstacle, namely Parallel GA, Hybrid GA, etc. These advanced GAs try to structure the populations into the number of subpopulations runnning parallel on processors [7], or to use heuristics of specific problems to improve the convergence speed [16]. But, these advances required huge resource of calculation facilaties or desiged for specific cases only. In the scope of adaptive bus signal priority control, this paper would like to present a heuristic approach to improve the convergence speed of the conventional GA. This heuristic approach is based on the compensation rule between consecutive cycle lengths assumed in adaptive signal control. The improved GA would contribute partly to a comprehensive view of how to faster the GA convergence speed when applied to the optimization problems of bus signal priority control systems.

2. Adaptive Bus Signal Priority Control

Since the purpose of this paper is to propose an improved genetic algorithm (GA) for adaptive networks, the paper investigates an adaptive bus priority control system for a signalized intersection only. The investigations into multi-signalized intersections, grid networks or other related factors are beyond the scope of this paper. Based on previous research studies about adaptive bus signal priority control in actuated system [14], this section would like to take an overview of the relationships as well as some constraints at a simple signalized intersection whose signal follows the National Electrical Manufacturers Association (NEMA) standard [19]. The definitions for the left-hand drive in Japan are as follows:

Table 1. Definitions of phases, rings and barrier

	Main phase		Cross phase	
Ring A	1	2	4	3
Ring B	6	5	7	8

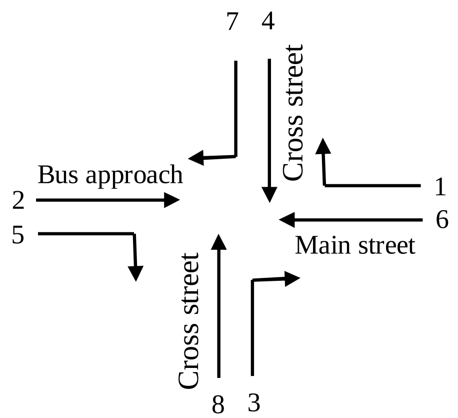


Figure 1. Standard NEMA phases, rings and barrier

There are several constraints for fixed cycle length intersections under NEMA operations. These constraints are nesseary and boundary conditions of objective fucntions in optimization problems. They include cycle length constraints, minimum green time constraints, barrier constraints, red-green relationships, etc [14]. Several typical constraints are briefly expressed in this section. For example, the fixed cycle length constraint for the lead-lead phase sequence is expressed as follows:

$$L_1 \cdot L_5 \left(C - \sum_{i=1}^{4} g_{ji} \right) = L_1 \cdot L_5 \left(C - \sum_{i=5}^{8} g_{ji} \right) = 0 \quad (1)$$

where

C: cycle length (s)

g_{ji}: the green duration of movement i, cycle j (s), j=1,2.

$$L_i = \begin{cases} 1 & \text{, if movement i is lead} \\ 0 & \text{, if movement i is lag} \end{cases} \text{, i=1, 3, 5, 7} \quad (2)$$

Similarly, concerning barrier and rings, the constraints are built based on the upper ring and bellow ring relationship. The upper ring and the below one at the same side of the barrier should have the same duration. The relationships are as follows:

$$\begin{cases} g_{j1} + g_{j2} = g_{j5} + g_{j6} \\ g_{j3} + g_{j4} = g_{j7} + g_{j8} \end{cases} \quad \text{j=1,2} \qquad (3)$$

In addition, as presented in HCM 2000 [11], the minimum green interval to ensure the walking time is calculated based on walking speed, effective crosswalk, number of pedestrians and the road width.

$$G_{\min,i} = 3.2 + \frac{L_i}{v_p} + \left(2.7\frac{n_p}{w_e}\right) \qquad (4)$$

where

L_i: is the width of the intersection at approach i (m)

v_p: is the average walking speed (m/s)

w_e is the effective width of the crosswalk (m)

n_p is the number of pedestrians

Related to bus signal priority control, there have been many research studies about it. The California PATH Center [9] has developed many models to improve bus service and minimize negative impacts on general vehicles at isolated signalized intersections, coordination arterials, ramp metering, etc. The diversity of related studies can be seen obviously. Some research studies developed the models based on bus queuing delay at traffic signals when triggering TSP requests [6] or minimizing the intersection delays [5], [14]. The development paid attention not only to heuristic algorithms [18], dynamic Programming Models [23], analytical approaches [15] but also practical approaches [21], [22]. The development was covered not only for a single request [6] but also for multi requests [4], [23] or for conflicting transit routes [5]. However, this paper ends in proposing an improved genetic algorithm to increase the convergence speed as well as analyzing the effects of the improved GA only. The research would not analyze deeply the model nor try to develop new models to improve the bus service.

The optimization model used in this research is assumed to include the movement splits in two consecutive signal cycles. The first cycle is the cycle in which the bus is predicted to come. This cycle is the controlled cycle in which the movement splits are divided following the optimal results of the optimization problem. The second cycle is the compensation cycle in which the movement splits are re-compromised to compensate for the lost time in the controlled cycle. The amount of movement splits in the compensation cycle are output from the optimization results, too. The illustration is shown in Figure 2.

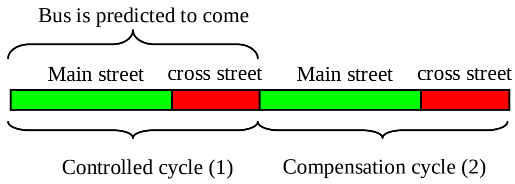
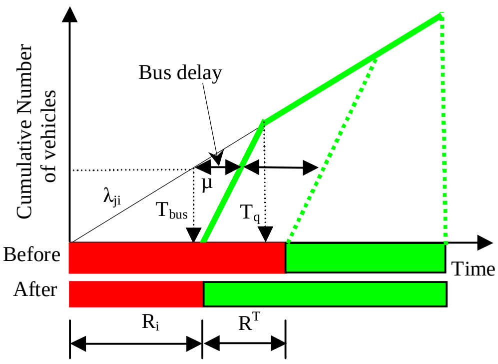


Figure 2. Considered consecutive signal cycles

In Japan, two signal timing techniques, including green extension and eargly green are popularly used [6]. Depending on the optimal results of the optimization task, these two techniques are applied to adaptively control the traffic signal once the bus approaches to the intersection. The optimization task is proposed to minimize the total delay in the two consecutive cycles in this research. With arrival rate λ_{ji}, saturation flow μ_i, the traffic delay and bus delay are calculated based on relationship as shown in Figure 3.



*Source: Li, M. [14]

Figure 3. Early green time technique

Assuming that there is no residual queue in each signal cycle, the total delay is calculated based on the bus delay and general traffic delay as mentioned in previous studies [14] as follows:

$$d = \sum_{i=1}^{8}\left[\frac{\mu_i}{2}\rho_i(r_{1i}+r_{2i})^2 - r_{2i}\mu_i \min(g_{1i}, \rho_i r_{1i})\right] + \phi \cdot w_b \frac{R_i}{T_q}\max(T_q - T_B, 0) \qquad (5)$$

where

$$\rho_{ji} = \frac{\lambda_{ji}}{\mu_i - \lambda_{ji}} \qquad (6)$$

λ_{ji}: is the arrival rate on approach i of cycle j

(veh/s)

μ_i: is the saturation rate on approach i (veh/s)

r_{ji}: is the red time for approach i of cycle j (s)

T_B: is bus arrival time at signal (which reference to the beginning of the red duration for the bus phase).

w_b: is the bus weight which is assumed to be 20 in this research.

ϕ: is a binary indicator to choose early green or green extension techniques. The indicator is as follows:

$$\phi = \begin{cases} 1 & \text{, if early green is applied} \\ 0 & \text{, otherwise} \end{cases} \quad (7)$$

Buses are assumed to come sparsely on approach 2 of the main street, the queue is dismissed at:

$$T_q = \frac{\mu_i}{\mu_i - \lambda_{ji}} R_i \quad (8)$$

In summary, once buses are detected by the road-side infrared beacon [22], the optimization algorithm determines the movement splits in the bus arrival cycle and in the compensation one. The optimization task is trying to minimize the total delay caused by granting priority to the bus. To get the results, the optimization task uses the improved genetic algorithm to find optimal sets of parameter which are sent to the traffic control center to modify the traffic signal to adapt to the current priority situation. The detail of the improved algorithm is shown in section 3.

3. Evolution Algorithm

To overcome the low convergence speed of the conventional GA, the paper introduces a new process of GA type determination. Considering a simple adaptive bus signal priority control based on the actuated system, the research tries to develop a GA to minimize the total control delay. As many actuated control systems in Japan, once a bus is detected by the infrared beacon setup upstream from the intersection [22], the signal control center will determine the optimal solution of signal timing to grant to the bus. The determination step shown in Figure 4 is proposed to use GAs in this research and should be a function of traffic state, bus occupancy, signal state, etc. Depending on the evaluation of the current traffic situation, the improved GA or conventional GA should be chosen for the optimization. The structure of the process is illustrated in Figure 4.

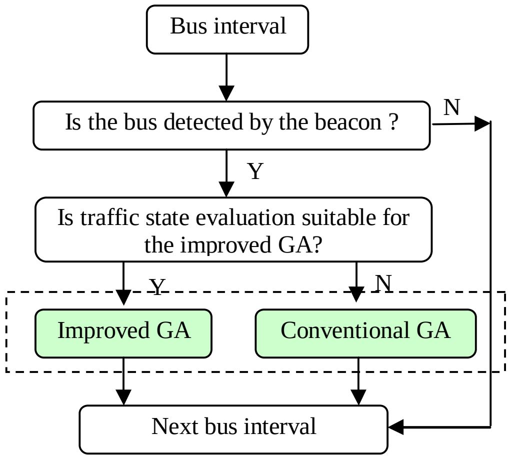


Figure 4. The process of GA type determination

The conventional GA shown in Figure 4 is introduced with its mechanism inspired by evolutionary biology such as inheritance, mutation, selection and crossover [2]. This robust global optimizer has been applied successfully for many research in the field of transportation [3], [7], [12]. Because of being premised on the evolutionary ideas of natural selection and genetic, this algorithm tries to eliminate the bad traits from the population through genetic process. From parameters (known as genes) needed for the estimation, the GA process joins them together to form a string of value (refered to as a chromosome). Each gene represents a specific trait of the organism. Using selection and applying genetic operators such as mutation and crossover, the GA creates new populations of solution from the initial population. Namely, the selection operator chooses the chromosomes randomly in the population for offspring reproduction. The crossover operator exchanges subsequences of two chromosomes to create offsprings [17]. The probability of crossover occuring is assumed to be 0.8 in this research. The process of crossover operator is illustrated as shown in Figure 5.

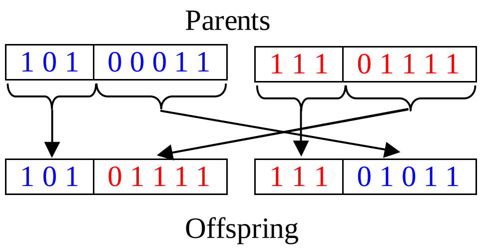


Figure 5. Crossover operator

After finishing the crossover operator, the mutation operator then randomly flips some bits in a chromosome in order to ensure genetic diversity within the population. The mutation probability proposed in this paper is 0.15. The illustrated figures of the mutation operator are as follows:

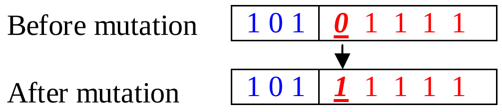


Figure 6. Mutation operator

The conventional GA process including population generation, fitness evaluation, individual selection, mutation, crossover is executed until reaching the the stop conditions. Once the stop conditions are satisfied, the best solution of parameter sets is used to control the traffic signal. The process of optimization is illustrated as in the following figure.

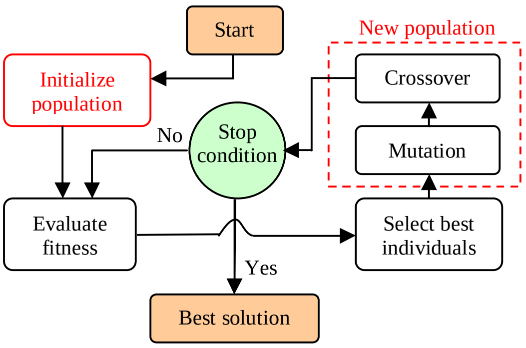


Figure 7. Conventional GA for optimization

As mentioned above, the conventional GA requires huge time to converge the optimal solution. Therefore, the paper would like to present an evolution algorithm to improve the convergence speed when optimizing delay in bus signal priority control. According to previous studies, the most important aspects of any genetic anforithm implementation are the fitness evaluation function and the reproduction scheme that must be mutually compatible [16]. The reproduction of new population is carefully concerned in this research. Because the general purpose of the optimization in adaptive control system is to compromise the movement splits to get the total minimum delay, the balance rule should be kept in terms of time delay. Once the first cycle is shrunk or extended, the second cycle will have a tendency to compensate the first cycle for time loss caused by the priority granted to bus. Let C_s, C_e be the constrained spaces of signal shrink and signal extension respectively, the population spaces of the first cycle (P_i) and the second one (P_{i+1}) in the conventional GA and the improved GA are illustrated as follows:

For the conventional GA:

$$P_i =< S,E >,\ P_{i+1} =< S,E > \tag{9a}$$

For the improved GA:

$$P_i + P_{i+1} =< S,E > \tag{9b}$$

where

S: Population space for signal shrink

$$S = \{s_u \mid u \in C_s\} \tag{9c}$$

E: Population space for signal extension

$$E = \{e_v \mid v \in C_e\} \tag{9d}$$

Relying on that relationship, the research tries to improve the convergence speed of the conventional GA by properly upgrading the reproduction of new populations to continue the genetic process. This tendency makes the new generated population narrow and distributed around the possible optimal points if the traffic evaluation step is good enough. Once the new population spaces contain optimal points as shown in Figure 8, the search engine of the improved GA to generate a number of citizens in such the narrowed population is therefore more effective than that of the conventional one. The illustration of this improvement is illustrated as in Figure 8.

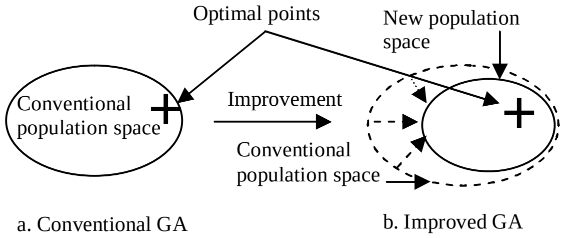


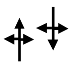
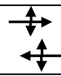
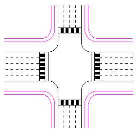
Figure 8. Population space improvement

Considering a case study at a simple signalized intersection, all information of the adaptive bus signal priority control such as the objective function, constraints, etc are coded in C++ language. Using the same characteristic parameters of genetic algorithms such as crossover probability, mutation probability, etc. for the computation processes of the conventional GA and the improved GA, the paper would like to present the advantages of the proposal. In terms of the computation time and the number of iterations for convergence, the performance of the improved GA is presented and comparatively analyzed as shown in following sections.

4. A Simple Numerical Test

The reseach conducts a numerical test with the real traffic information of an intersection in Nagaoka, Niigata, Japan. The main street and cross street of this intersection have four lanes. There are right-turn lanes on each approach. For simplicity, the research assumed the constant arrival rates as well as constant saturation flows. By analyzing recorded videos at the studied intersection, the average flow rates on each movement as well as real signal information (8:00-9:00 AM, May 13rd, 2010) are simplified into two phases as shown in the following table and figure.

Table 2. Traffic signal at the studied intersection

		
G = 54s Y = 4s R = 3s	G = 62s Y = 4s R = 3s	
Flow rates for each movements (vps)		
λ_1=0.011	λ_2=0.103	λ_3=0.023
λ_4=0.154	λ_5=0.038	λ_6=0.070
λ_7=0.020	λ_8=0.143	μ_i=1.250

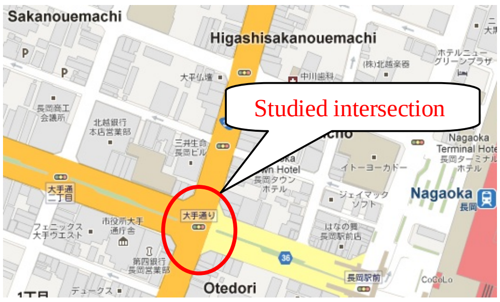


Figure 9. The studied intersection

Assuming the bus arrival time on local clock [14] T_B of 25s, the optimization processes are graphed for two scenarios tested in this paper. The first scenario uses the conventional GA to find the optimal set of parameters and the second one is applied with the improved GA. With the studied traffic situation, the results show that after around 10-20 iterations, the nearly stable solutions are achieved. As shown in Figure 10, the changes of the optimized delays over the number of iterations can be compared clearly. The figure shows that the convergence rate of the improved GA is faster than that of the conventional GA. The details are shown in the following figure:

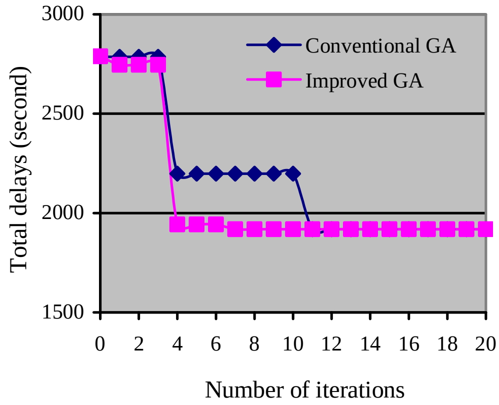


Figure 10. The convergence speed comparison

It is clearly illustrated in Figure 10 that, the improved GA has a faster convergence speed. The improved GA converges after 6 interations. Meanwhile the figure is up to 10 in the conventional GA case. In addition, because the computation time to achieve the optimal result is an important factor, the paper would like to compare the amount of time needed for each iteration in the two cases. Assuming that the stop condition is the number of iterations with its figure of 200 iterations, the paper conducts the computations in a computer whose configurations are 0.99GB of RAM, Core 2 CPU, T7200 @2.00GHz. Converted from stair charts output by the programs, the computation times are compared as follows:

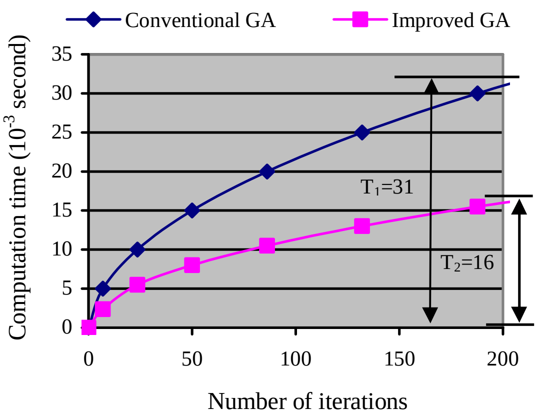


Figure 11. The computation time comparison

With the accuracy analysis of millisecond, the computation time in the case of improved GA is usually smaller than that in the conventional GA as shown in Figure 11. After 200 iterations, it takes T1=31 milliseconds for the conventional GA to converge to a nearly optimal delay of

1798.38s. Meanwhile, the improved GA lost 16 milliseconds only to get a better nearly optimal delay of 1797.99s. It can be said that, the improved GA is better than the conventional one in terms of computation time. Compared with the conventional GA, the improved algorithm can reduce the computation time by up to 48.39% after 200 iterations. On an average, each iteration can save 75 microseconds if the improved GA is applied. The saving time benefits the smoothness of any simulation animation. It is especially necessary for real time control which requires small computation time.

As mentioned above, the idea to improve GAs for adaptive bus signal priority control is based on the compensation rule between the consecutive cycles. This rule is sometimes ruined by the different levels of the total delays in the first cycle and in the second one. According to Figure 4, to choose which GAs, improved GA or conventional GA, is the proper algorithm at a certain traffic situation, the step of traffic evaluation is extremely important. This step should be depended on many factors. However, for the purpose of GA algorithm improvement, the research simply assumes that only saturation degrees on the main street and cross street are related fators. The saturation degree [11] for movement i is defined as follows:

$$\chi_i = \frac{\lambda_i}{\mu_i} \tag{10}$$

where

λ_i : Arrival flow rate for movement i (veh/s)

μ_i : Saturation flow rate for movement i (veh/s)

The performance of the improved GA is compared with that of the conventional GA by introducing the concept of convergence rate improvement. The convergence rate improvement is defined as the average ratio of the reduced delays benefited by applying the improved GA to the initial delays optimized by using the conventional GA.

$$R = \frac{\sum_{i=1}^{N}\left(\frac{(C_i - I_i)\cdot 100\%}{C_i}\right)}{N} \tag{11}$$

where

R: The convergence rate improvement (%)

C_i : The optimal delay at iteration i optimized by the conventional GA (s)

I_i : The optimal delay at iteration i optimized by the improved GA (s)

N: The number of considered iterations

Based on the convergence rates of the two GAs, the research identifies that most of them converge to stable points after 10-20 iterations. However, for valid comparisons, the paper investigates 200 iterations for each type of GA. The demand based efficiency of the improved GA is shown as in the following figure.

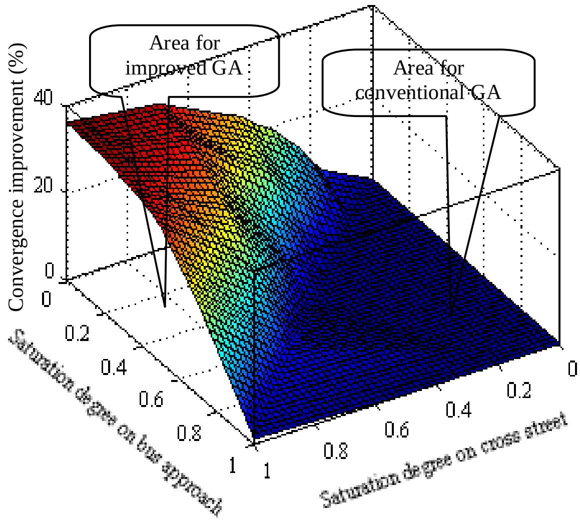


Figure 12. The demand based efficiency

The figure shows the performance of the proposed genetic algorithm when traffic saturation degrees change. As shown clearly in the figure, the improved GA are successful at most of the points where the saturation degree on the cross street is higher than that on the main street (bus approach). These success points present that the improved GA can perform a better convergence speed compared with the conventional GA. The convergence rate improvement can reach to 36.2% in situations of high saturation degrees on cross street and small ones on the main street. On the contrary, when the saturation degree on the main street is higher than that on the cross street, the damage of compensation rule caused by the big difference in traffic demand occurs. The failure makes the slower convergence rate in the improved GA when compared with the conventional one. Therefore, the conventional GA is suggested to use for this area as proposed in Figure 12.

5. Conclusion and Future Research

The paper aims at three targets. The first target is to propose an improved genetic algorithm (GA) for optimization in adaptive bus-signal priority control at signalized intersections. Based on the compensation rule between signal cycles in adaptive control, the paper suggests an improved GA that can increase the convergence rate to reach the optimal solutions. The convergence speed of the proposed GA is then compared with that of the conventional GA. The faster convergence speed reduces the computation time, which is very important to signal control in complicated networks. Secondly, the paper would like to present a way to apply the algorithm to a simple adaptive bus-signal priority control system as well as compare the amount of time saved when applying the improved algorithm. The result shows that after 200 iterations, the improved GA can save the computation time by 48.39%. This time saving is important to the smooth running of any simulation model as well as real time control systems. Then the research thirdly investigates the efficiency of the proposed algorithm under various values of traffic saturation degree. The results show the improvement of the proposed GA when compared with the conventional GA. The improvement can be up to 36.2% in the positive extreme cases. This improvement becomes significant when the saturation degree on the cross street is higher than that on the main street.

For the purpose of algorithm evaluations, the numerical test is rather simple in this paper. To recognize clearly the benefits of the improved GA, the bus-signal priority control should be considered at a larger network scale or at a more complicated level. In addition, the traffic evaluation step to choose which genetic algorithms is critical to the success of the proposal. However, it was assumed simply in this research with the saturation degrees as related factors. A more comprehensive survey should be dealt with other factors such as bus occupancy, number of stops, queue length, etc. These shortcomings are expected to be concerned in the studies to follow.

Although the improved GA can reduce the computation time significantly, the effect of the improved GA is still modest. The application is suitable in the cases where the saturation degree on cross street is higher than that on the main street only. Moreover, the main limitation of the improved GA is that the algorithm is bound in adaptive signal control, where the compensation rule between signal cycles is the important factor for the algorithm. For negative extreme cases in which the compensation rule does not occur, the convergence rate of the proposed GA improves insignificantly when compared with that of the conventional GA. Therefore, a further improvement of the genetic algorithm for bus-signal priority control to get a better convergence rate should be a target of future studies.

Acknowledgments

The authors highly appreciate the contributions of professors at Nagaoka University of Technology as well as valuable suggestions from anonymous authors in improving the quality of the paper.

References

[1] Ayad, M. T., Mohd, S. A. and Mohd, Z. M. Y., The Use of Genetic Algorithm for Traffic light and Pedestrian Crossing Control, International Journal of Computer Science and Network Security, Vol.9, No.2 (2009).

[2] David, B., David, R., Ralph, R.M., An overview of genetic algorithm, University Computing, 15(2), pp58-69 (1993).

[3] Der-Hong, L., Xu, Y., Chandrasekar, P., Parameter Calibration for Paramics Using Genetic Algorithm, TRB, ID Number: 01-2399 (2001).

[4] Der-Horng L., Wei H., A new methodology for multi-level bus prioritization at signalized intersections, TRB Annual Meeting CD-ROOM (2005).

[5] Eleni C. and Alexander. S., Traffic Signal Optimization with Transit Signal Priority: Application to an Isolated intersection , TRB Annual Meeting (2011).

[6] Geetha, N., W., Shamas, u. I. B., Masao, K. and Majid, S., An improved Bus signal Priority Model, Seisan-kenkyu, Vol.60, No.4, p.59-63, (2008).

[7] Guangwei, Z., Albert, G. and Shen, L.D., Optimization of adaptive transit signal priority using parallel Genetic Algorithm, Tsinghua science and technology, ISSN 1007-0214 02/14, pp131-140, Vol.12, No.2 (2007).

[8] Halim, C., Michael, G.H. B., Traffic signal timing optimisation based on genetic algorithm approach, including drivers'routing, Transportation Research Part B 38, 329-342, (2004).

[9] Henry X.L., Lianyu. C., Will. R., Paramics API Development Document for Actual

Signal, Signal Coordination and Ramp Control, California PATH ATMIS Center, University of California, Irvine, (2003).

[10] Heydar, T. S., Mohsen, K. and Mahsa, D., Intelligent Transport System based on Genetic Algorithm, World Applied Sciences Journal 6 (7): 908-913 (2009).

[11] Highway Capacity Manual, TRB, National Research Council, Washington D.C.,USA (2000).

[12] Jitendra, A. and Tom, V.M., Transit Route Network Design Using Parallel Genetic Algorithm, Journal of computing in civil engineering (ASCE), Vol.18, No.3 (2004).

[13] Leena, S., et al., Time Optimization for Traffic Signal Control Using Genetic Algorithm, International Journal of Recent Trends in Engineering, Vol.2, No.2 (2009).

[14] Li, M., Development and applications of adaptive transit signal priority system, doctoral Dissertation, (2010).

[15] Liu, H., Zhang, J. and Cheng, D., Analytical Approach to Evaluating Transit Signal Priority, Journal of Transportation systems engineering and information technology, Vol.8, Issue 2 (2008).

[16] Liviu, C. and Andreea, D., Public Transport Route Finding using Hybrid Genetic Algorithm, Informative Economicca, Vol.15, No.1 (2011)

[17] Melanie, M., Genetic Algorithm Overview, Santa Fe Institute, (1995).

[18] Qing H., K Larry, H., Jun, D., A Heuristic algorithm for Priority traffic signal control, TRB Annual Meeting (2011).

[19] Regina, M., Traffic signal timing manual, U.S. Department of Transportation, Federal Highway Administration, Publication Number: FHWA-HOP-08-024, June (2008).

[20] Richard, J.P. and Xin, F., Improving genetic algorithms perforamce by hashing fitness values, Department of Electrical and Computer Engineering, Marquette University, USA

[21] Rui W., Sunghyu, B., Okamura, T., Nakamura, F., A practical approach for design of bus signal priority strategy, 12th WCTR, Lisbon, Portugal (2010).

[22] Ryohei, T., et al., Trial Operation of a new public transportation Prirority system using Infrared beacons for two-way communication, 3rd Annual World Congress on ITS, Orland (1996).

[23] Wanjing M., Yue, L., Xiao-Guang, Y., A dynamic Programming Model for Bus Signal Priority with Multi request, TRB Annual Meeting (2011).

Tran Vu Tu *is a doctoral student in the Department of Civil and Environmental Engineering at Nagaoka University of Technology, Japan. He achieved a Master's degree in Transportation Engineering at the current university. Before coming to Japan, he worked as a lecturer in the department of civil engineering, Saigon Technology University (STU), Vietnam. His research interests are traffic engineering, traffic simulation, Transit Priority System, network analysis, discrete choice model, mathematical optimization. He has published numerous journals and proceedings as well as co-authored many research papers in the related fields.*

Kazushi Sano *is an Associate Professor in the Department of Civil and Environmental Engineering at Nagaoka University of Technology (NUT), Japan. Dr. Sano received a doctoral degree in Doctor of Engineering in Traffic Engineering and Land Planning. He has published numerous papers and reports in such journals and proceedings as Academic Journal, Advanced Transgraft Telematics/Intelligent Vehicle-Highway Systems, or Application of Artificial Intelligence in Engineering. His research interests are in the area of traffic engineering, traffic simulation, public transport system, and land planning.*