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ENHANCED-GA SUPPORTS TRAFFIC SIGNAL OPTIMIZATIONS AND PROTECTS THE URBAN ENVIRONMENT

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Abstract. Much current research on traffic signal optimization often neglects the impact of environmental factors in urban areas. This can result in suboptimal solutions that do not consider the effects of traffic on air pollution and the overall urban environment. To address this issue, this article proposes a solution that combines Enhanced GA with a comprehensive framework for considering environmental factors in traffic signal optimization. By optimizing traffic signal timings and minimizing emissions, the proposed solution aims to reduce congestion and improve urban transportation networks' efficiency while protecting the environment. The proposed approach uses a set of optimization algorithms and assumptions to generate a comprehensive framework for traffic signal optimization. These algorithms and assumptions consider environmental factors such as air quality and the impact of traffic on the local ecosystem. Moreover, this article provided the enhanced genetic algorithm operators and suggested model formulation that could be applied in other research on traffic signal optimization directly to reduce calculation times and increase the efficiency of the novel suggested models.

Keywords: Traffic control, single- multiple objective genetic algorithms, vehicle exhausted emission, traffic optimization.

1. INTRODUCTION

Urbanization is a critical issue that brings various negative effects on urban life [1]. The challenges include difficulties in managing urban waste, improving transportation and communication systems, maintaining the city's infrastructure, and ensuring urban environmental protection policies. The constant movement of vehicles on a daily basis significantly undermines the quality of life for citizens, environmental protection, and urban areas' financial capacity. The capacity limitation of road networks restricts private vehicles' growth and the transportation networks serving urban areas. Expanding the traffic networks or increasing the complexity of relying on signal control systems is an unsustainable approach to address traffic congestion, particularly in developed countries. Therefore, the process of enhancing the timing of traffic signals is an essential solution to address traffic jams and support intelligent transport system (ITS) concepts for generating smart city visions [2]. Traffic signalized optimization is critical regarding Intelligent Transportation Systems (ITS) implemented in urban regions, and numerous scholars or a variety of experts have focused on developing innovative approaches or new techniques to optimize traffic signals at isolated intersections to tackle traffic congestion.

The intersection and the traffic light control system play a vital role in ensuring safety and optimizing traffic flow for both vehicles and pedestrians [3]. A signalized intersection in arterial roads or traffic networks has a significant interconnection with neighboring intersections [4]. A few studies have attempted to improve traffic control systems by optimizing single effective objectives at signalized intersections, such as other factors influenced by signalized intersections include the overall traffic capacity, intersection throughput, travel time, congestion levels, and the overall efficiency of the transportation system. However, a single-objective traffic signal optimization approach may have negative impacts on other objectives. Therefore, a suggested formulation model should emphasize the application of multi-objective optimization in the field of traffic control and traffic management [5, 6].

Several studies have the introduction of a recommended approach for multi-objective optimization approaches to address traffic congestion at signalized intersections [7, 8]. The approaches aimed to optimize more than two effective objectives, such as throughput vehicle, the average duration of delays, fuel usage, traffic flow consistency, and the count of vehicle stops, queue ratio, and traffic capacity. However, recent research work needs to consider the conducting a comprehensive examination of traffic effectiveness, traffic safety, and environmental considerations simultaneously. The suggested research endeavor aims to develop a comprehensive framework for traffic signal optimization by considering environmental factors such as air quality and the impact of traffic on the local ecosystem. The research work proposes an Enhanced GA approach that optimizes traffic signal timings and minimizes emissions to reduce congestion and improve urban transportation networks' efficiency while protecting the environment. The research work utilizes a set of optimization algorithms and assumptions to build an all-encompassing framework for optimizing traffic signal operations. The proposed model formulation and Enhanced GA operators could be applied directly to reduce calculation times and increase the efficiency of novel suggested models. This research work will contribute to the development of sustainable urban traffic systems that consider both traffic efficiency and environmental protection.

The following study aims to put forward an innovative methodology or suggest a fresh approach to optimize traffic signal operations while considering or incorporating the following factors the impact of environmental factors in urban areas. Specifically, this study will introduce the EGA and the comprehensive framework for traffic signal optimization that considers environmental factors. The first section of this study will provide an in-depth explanation of the EGA and how it can be used to optimize traffic signal timings while minimizing emissions. The second section will detail the experimental process used to validate the proposed solution's effectiveness, including data collection, model formulation, and simulation experiments. Finally, the study will conclude by presenting the results of the experiments and discussing the practical implications of the proposed solution. This study's contributions will provide a comprehensive framework for traffic signal optimization that considers environmental factors, leading to more efficient and sustainable urban transportation systems.

2. GENERATION OF PROPOSED MODEL FORMULATION

2.1. Proposed model

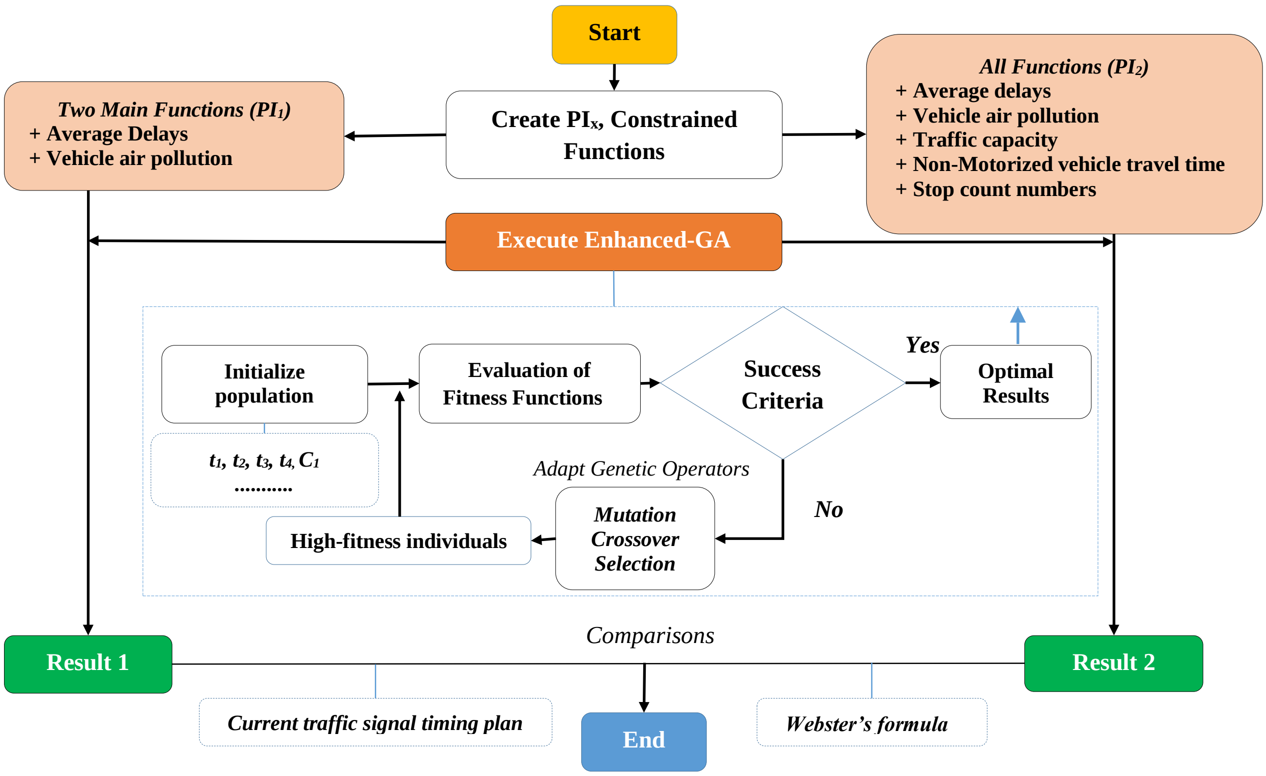


Figure 1. The suggested model formulation.

The proposed formulation of the model was made to handle the mentioned issues above (Figure 1). One approach involves using fitness functions to measure the effectiveness of different transportation strategies. The variables are the duration of efficient green time (t_{ij}) assigned to each phase and the corresponding cycle time (C). In the enhance-GA technique, the variable is a gene of the chromosome.

Initially, this research starts by defining a fitness function 1 (PI_1), which focuses on two main factors: average delay and vehicle exhausted emission. These metrics are essential for assessing the efficiency and environmental impact of transportation systems. As the research advances, a more comprehensive fitness function 2 (PI_2) is developed. This new fitness function incorporates additional parameters to provide a more holistic evaluation. In addition to average delay and vehicle exhausted emission, it includes the count of vehicle halts, traffic carrying capacity, and delay experienced by non-motorized vehicles. This expanded fitness function allows for a more thorough assessment of transportation systems, taking into account factors such as congestion, capacity, and the impact on non-motorized modes of transport.

To optimize the transportation systems and find the best solutions, this research applies constrained optimizations. These optimizations consider various constraints and limitations, such as road capacities and environmental regulations, while striving to reduce the values of the fitness function.

To assess the effectiveness of the system's performance of the optimization algorithms, an enhanced Genetic Algorithm (GA) is employed. The fitness function 1 and fitness function 2 are separately input into the GA, which runs simulations to find optimal solutions. The results obtained from running the GA with fitness function 1 are referred to as result 1, while the results obtained with fitness function 2 are referred to as result 2.

In the final step of the research process, the results from the two fitness functions, result 1 and result 2, are compared to assess the performance of different transportation strategies. This comparison helps researchers understand the trade-offs and advantages of different approaches and aids in identifying the most effective strategies for minimizing delays, reducing vehicle emissions, optimizing traffic flow, and considering the needs of non-motorized transportation modes.

2.2. Fitness Functions

One commonly proposed objective function, that measure traffic efficiency, is represented by the average delay experienced under control conditions function discussed in multiple studies. The function aims to simulate the level of effectiveness in managing traffic flow and is represented by the following mathematical expression [9].

$$AD_{\mathrm{I}} = \frac{\sum_{i=1}^{n}\sum_{j=1}^{m}\left\{\left[\frac{0.5\left(1-\frac{t_{ij,lg}}{C}\right)^{2}}{1-\left[\frac{\min\left(1, X_{ij,lg}\right)t_{ij,lg}}{C}\right]}+900T\left[\left(X_{ij,lg}-1\right)+\sqrt{(X_{i,lg}-1)^{2}+\frac{8kIX_{ij,lg}}{c_{ij,lg}T}}\right]\right]v_{ij}\right\}}{\sum_{i=1}^{n}\sum_{j=1}^{m}v_{ij}} \tag{1}$$

Where: AD represents the average vehicle delay (s), C_{ij} corresponds to the cycle time In phase i and lane group j, the effective green times are denoted by t, the traffic flow-to-capacity ratio is represented by X, and the analysis period is indicated by T (which is 15 minutes or 0.25 hours in this case study), the incremental delay factor is denoted by k, the upstream filtering adjustment factor is represented by I, and the traffic flow is indicated by v, $\sum_i \left(\frac{v}{s}\right)_{ci}$ symbol represents the cumulative value of the traffic flow ratio for the critical lane group, X_c symbol represents the threshold or critical value of the flow-to-capacity ratio (v/c), and y_i symbol y_i represents the proportion of the actual traffic volume to the capacity of the traffic flow (S_{ij}).

As previously discussed, city governments prioritize environmental protection and the preservation of urban life when formulating policies. Therefore, several researchers have dedicated their endeavors to create a comprehensive model capable of evaluating the impacts of fuel consumption and vehicle emissions, and pedestrian delay time [10, 11]. In line with these ongoing studies, we present a hypothetical model formulation that incorporates vehicle exhaust emissions (E_i), as depicted by the following equation [12, 13].

$$E_I = \sum_{j=1}^{n} \left(EF_{ij}^{PCU}.q_j.L_j + \frac{1}{3600}.EFI_{ij}^{PCU}.q_j.d_j \right) \tag{2}$$

Where: EF_{ij}^{PCU} Refers to the emission factor of a standard car unit, measured in grams per passenger car unit per hour (g/(pcu.h), EFI_{ij}^{PCU} is the Standard Car Unit Idling Emission Factor (g/(pcu.km), q_j is the traffic arrival, traffic flow of lane group j, d_j represents the mean delay experienced by vehicles in lane group j. Several research studies have identified the traffic capacity function [14, 15] and the number of stops function [13, 16] as key factors for maximizing traffic capacity and minimizing vehicle stops [14, 15].

$$C_{ap} = \sum_{i=1}^{n} S_{ij} \frac{t_{ij}}{C} \tag{3}$$

$$H_I = 0.9 \sum_{i=1}^{n} q_i . \left(\frac{1 - {}^{t_{ij}}/_{C}}{1 - y_i} \right) \tag{4}$$

Furthermore, it is crucial for signalized intersections to provide equitable service to both motorized and non-motorized vehicles, as emphasized in previous research [17]. Therefore, this study introduces the optimization of non-motorized delay time (NTD_I) as an objective function, which is formulated as a fitness function based on equation [18].

$$NTD_I = \frac{\sum_{i=1}^{n} \sum_{j=1}^{m} \left(\frac{r_i C (1-\lambda_i)^2}{2(r_i - \bar{p}_{ij}} \right) \bar{p}_{ij}}{\sum_{i=1}^{n} \sum_{j=1}^{m} \bar{p}_{ij}} \tag{5}$$

Where: $\mathbf{r_i}$ denotes the maximum capacity of pedestrians crossing the road, $\bar{p}_{ij}$ represents the rate at which non-motorized vehicles arrive during the i-th phase and lane group j.

The provided model incorporates a normalized function as the fitness functions, accompanied by assigned weights to represent considerations encompassing traffic safety, optimizing traffic flow, and addressing environmental factors. This is expressed through the following 2 types of formulas:

The first fitness function PI_1 includes average delay and vehicle exhausted emission functions.

$$\text{Min } PI_1 = \min \left(\alpha \sum_{i=1}^{n} \frac{AD_I}{AD_0} + \beta \sum_{i=1}^{n} \frac{E_I}{E_0} \right) \tag{6}$$

The second fitness function includes the average delay function, traffic capacity, number of stops, non-motorized vehicle delay, and vehicle emission functions.

$$\text{Min } PI_2 = \min \left(\alpha \left(\sum_{i=1}^{n} \frac{AD_I}{AD_0} + \left(\sum_{i=1}^{n} - \frac{C_{ap}}{C_{ap0}} \right) + \sum_{i=1}^{n} \frac{H_I}{H_0} + \sum_{i=1}^{n} \frac{NTD_I}{NTD_0} \right) + \beta \sum_{i=1}^{n} \frac{E_I}{E_0} \right) \tag{7}$$

Where: AD_0, NTD_0, H_0, C_{ap0}, E_0 denote the initial states assigned to various parameters, namely the average vehicle delay, the delay of non-motorized vehicles, the count of halts, traffic carrying ability, and the emissions from vehicle exhaust. The alpha (α) and beta (β) values present the weight of each function in the normalized function. Alpha (α) is the weight of the traffic safety, traffic efficiency, while beta (β) is the weight of the vehicle exhaust emission and (α+ β =1).

2.3. Bounded variables

In order to shorten the computation time and avoid the local optimal values, the proposed model in the paper added additional conditions to limit the optimal region. There are quite a few studies that skip or assume the values of lower and upper bound. This led to the suggested model being stuck at the local optimization values [19-21]. This research proposes to limit the feasible solution for optimal effective green time and corresponding lamp cycle time according to the following matrix.

$$LB^T = [min\ t_{ij1}, min\ t_{ij2}, min\ t_{ij3}, min\ t_{ij4}, min\ C_i] \quad (8)$$

$$UB^T= [max\ t_{ij1}, max\ t_{ij2}, max\ t_{ij3}, max\ t_{ij4}, max\ C_i] \quad (9)$$

Where: LB and UB represent the minimum and maximum limits of the variables (tij and Ci) simultaneously. The minimum and maximum values of tij, Ci could find in [9, 22, 23].

2.4. Enhanced-GA

Advanced Genetic Algorithms (EGA) are quite popular in the field of optimization [24]. However, there are not too many studies that clearly show how to optimize traffic signal timing for isolated intersections and reduce emissions simultaneously. The EGA incorporates advanced operators to enhance the evolutionary process and improve the search for optimal solutions. These operators include:

Elite Selection: This operator guarantees the direct transfer of the top-performing individuals from the present population to the succeeding generation without undergoing any genetic modifications. By preserving the best solutions, elite selection maintains the progress made and prevents the loss of valuable genetic material.

Adaptive Crossover: The adaptive crossover operator dynamically adjusts the crossover rate during the evolutionary process. It allows the algorithm to explore a broader search space by increasing the crossover rate when the population converges slowly and decreasing it when the convergence is fast. This adaptive mechanism balances exploration and exploitation to improve the overall search efficiency.

Adaptive Mutation: Similar to adaptive crossover, the adaptive mutation operator adjusts the mutation rate based on the current state of the population. It increases the mutation rate when the population diversity is low, encouraging exploration of new solutions. Conversely, it decreases the mutation rate when the population is diverse, promoting exploitation of promising areas in the search space.

Local Search: The local search operator aims to fine-tune the solutions in the population by performing a local optimization procedure. It applies a problem-specific optimization algorithm, such as gradient descent or hill climbing, to refine the solutions and improve their fitness values. Local search helps in fine-tuning the solutions and can lead to improved convergence and accuracy.

These operators in the Enhanced GA contribute to a more robust and efficient search for optimal solutions. Elite selection preserves the best solutions, adaptive crossover and mutation adaptively adjust exploration and exploitation, and local search refines the solutions. By leveraging these advanced operators, the Enhanced GA enhances the the capability and efficiency of the genetic algorithm in addressing intricate optimization problems.

The fitness functions PI_1 and PI_2 are evaluated for each individual among the individuals within the population. The selection, crossover, and mutation operators serve as the essential components then applied to generate new offspring. The selection operator favors individuals with higher fitness values, promoting the preservation of good solutions. Crossover combines genetic material from parent individuals to create offspring with potentially better characteristics. Mutation introduces stochastic modifications to the genetic material, enabling the exploration of novel regions within the search space. These operators are applied iteratively to evolve the population and improve the quality of solutions. The EGA offers a promising approach for solving complex optimization problems and demonstrates its effectiveness through a case study presented in this research article.

3. IMPLEMENTATION

3.1. Case Study

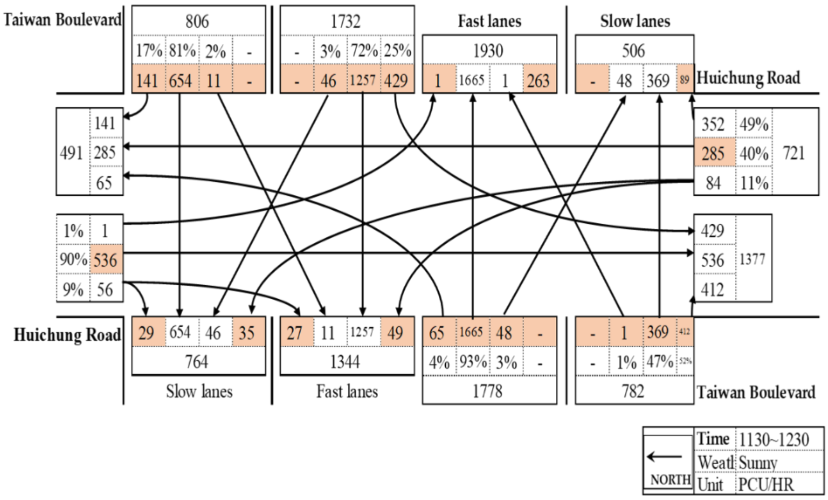


Figure 2. Turning movements and traffic flows of Taiwan Boulevard - Huichung Road Intersection, Taichung City in Asia

The city of Taichung in in Asia experiences a high number of individual automobiles and motorcycles, particularly in the area of Taichung City (Figure 2). The main means of public transportation is a bus network operating within the road infrastructure. As a result, traffic congestion is a frequent occurrence during rush hours. To address this issue, the city government has provided support to experts in the field of transportation engineering and scholars specializing in traffic studies collaborating to optimize the efficiency of signalized intersections.

During peak hours, traffic congestion has been a significant problem at the Taiwan Blvd-Huichung Rd intersection. To conduct this research, traffic volume data was collected directly from video detectors. The data was extracted specifically for the period from 11:30 to 12:30 during peak hours for 4 consecutive weeks. The traffic signal system in place at the intersection of Taiwan boulevard - Huichung Road intersection consists of four distinct phases, each accompanied by a detailed turn-by-turn diagram. The cycle length of the current signal control, determined by an experienced traffic engineer, is set at 180 seconds, which is considered appropriate for an intersection of this nature in an urban setting.

To gather data for analysis, video detectors were used to randomly observe traffic at the intersection. From this raw data, the rate of incoming vehicles was determined by dividing the total number of vehicles that arrived during the data collection period by the duration of that specific period. In order to facilitate analysis, the different types of vehicles observed were converted into a common metric known as Passenger Car Units (PCU). This conversion allowed for a standardized measure of the traffic flow and composition throughout the course of the study.

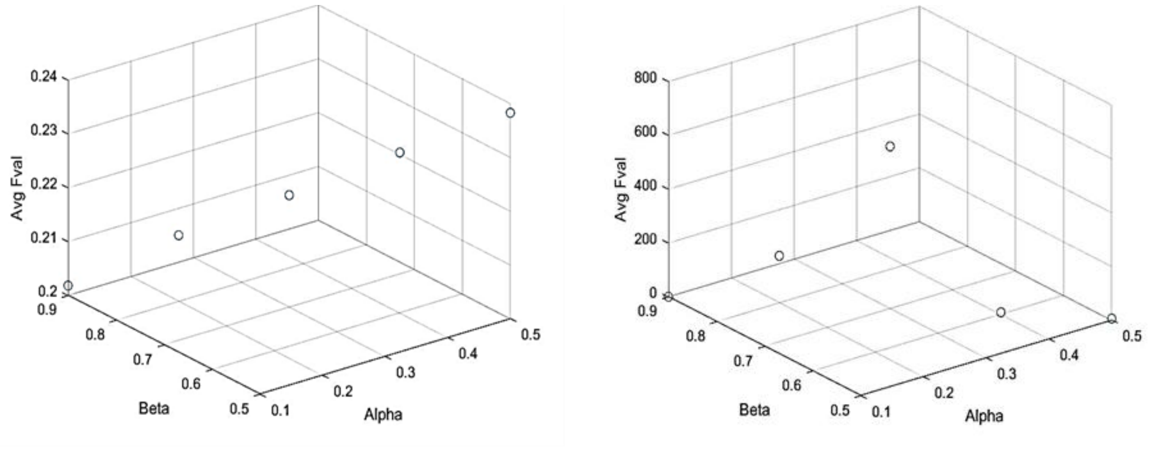
3.2. Results Evaluation

The proposed model applied to enhance the efficiency of the traffic signal system. for the Taiwan Boulevard-Huichung road intersection. The enhanced GA algorithm ran 50 different runs, then calculated the averages (avg) of the variables, the fitness function PI1, PI2, and calculated the corresponding standard deviation (std). In this model, we also changed the values of alpha (α) and beta (β) weights to find the best-fit fitness function. To demonstrate the importance of limiting the feasible solution by LB and UB that ignore in most of the research, this article operates the enhanced GA for PI1, and PI2 in two cases:

i) Unbounded Variables (Operating model together with LB, UB).

ii) Bounded Variables (Operating model without LB, UB).

- ***Unbounded variables:***



(a) PI_1 (b) PI_2

Figure 3. Correlation between alpha, beta, and fitness function in case of unbounded variables.

Table 1. The average values of effective green time (t_{ij}), cycle time (C_i), fitness functions, and corresponding standard deviation in case of unbounded variables for PI_1

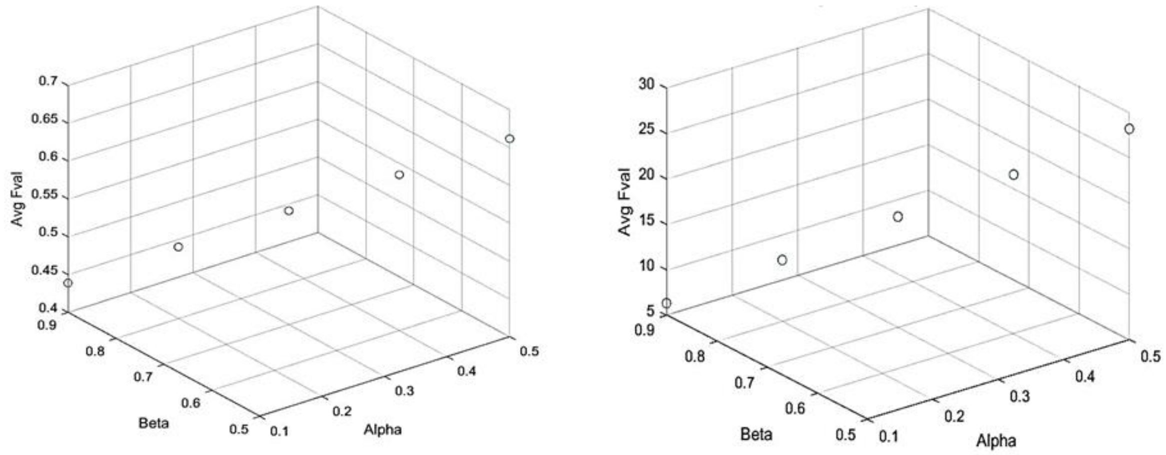
	No.	Alpha	Beta	t1 (avg)	t1 (std)	t2 (avg)	t2 (std)	t3 (avg)	t3 (std)	t4 (avg)	t4 (std)	C (avg)	C (std)	fval (avg)	fval (std)
PI_1	1	0.1	0.9	-0.030	0.889	-8.551	5.226	-0.018	0.528	-7.467	5.217	-0.064	1.942	0.202	0.007
	2	0.2	0.8	0.053	1.021	-8.778	6.156	0.031	0.606	-7.191	6.306	0.116	2.229	0.212	0.005
	3	0.3	0.7	0.408	1.782	-7.327	9.294	0.242	1.058	-8.433	9.161	0.891	3.890	0.221	0.014
	4	0.4	0.6	-0.098	0.817	-7.530	7.522	-0.058	0.485	-8.528	7.573	-0.214	1.784	0.230	0.009
	5	0.5	0.5	-0.078	1.363	-5.853	7.160	-0.046	0.809	-10.192	6.974	-0.169	2.976	0.238	0.018

Table 2. The average values of effective green time (t_{ij}), cycle time (C_j), fitness functions, and corresponding standard deviation in case of unbounded variables for PI_2.

	No.	Alpha	Beta	t1 (avg)	t1 (std)	t2 (avg)	t2 (std)	t3 (avg)	t3 (std)	t4 (avg)	t4 (std)	C (avg)	C (std)	fval (avg)	fval (std)
PI_2	1	0.1	0.9	0.039	0.871	-6.420	10.479	0.023	0.518	-9.557	10.524	0.085	1.903	1.142	1.990
	2	0.5	0.5	0.009	0.516	-7.370	8.048	0.005	0.306	-8.625	8.062	0.020	1.126	5.373	17.650
	3	0.4	0.6	0.034	0.636	-9.304	6.427	0.020	0.378	-6.676	6.361	0.075	1.388	6.958	38.301
	4	0.2	0.8	0.228	1.274	-10.629	8.455	0.135	0.757	-5.237	8.645	0.497	2.781	174.244	1218.800
	5	0.3	0.7	0.094	1.101	-8.042	6.587	0.056	0.654	-7.902	6.794	0.205	2.404	602.041	4247.600

According to Figure 3, Tables 1 and 2, it is easy to see that the results of effective green times (t_{ij}) and the optimal cycle length (C_i) are completely inconsistent with the current situation of traffic signal timing of the Taiwan Boulevard- Huichung Road intersection for four-phase movements after implementing the EGA with 50 different test times. In addition, the standard deviation (std) is also quite large for all the variables (t_{ij} and C_i), which means that it is very difficult for the EGA to avoid the local optimal region to find the global optimization values for both established objective functions. Furthermore, the optimal values and standard deviations aren't dependent on changing the weights representing traffic safety, traffic efficiency (α), and emission (β).

- ***Bounded variables:***



(a) PI_1 (b) PI_2

Figure 4. Correlation between alpha, beta, and fitness function in case of bounded variables.

Table 3. The average values of effective green time (t_{ij}), cycle time (C_i), fitness functions, and corresponding standard deviation in case of unbounded variables for PI_1.

	No.	Alpha	Beta	t1 (avg)	t1 (std)	t2 (avg)	t2 (std)	t3 (avg)	t3 (std)	t4 (avg)	t4 (std)	C (avg)	C (std)	fval (avg)	fval (std)
PI_1	1	0.1	0.9	74.708	0.785	17.278	0.479	44.367	0.466	10.764	0.549	163.118	1.713	0.439	0.003
	2	0.2	0.8	74.668	0.770	17.197	1.366	44.343	0.457	10.820	1.351	163.030	1.680	0.495	0.003
	3	0.3	0.7	74.666	1.300	17.247	1.834	44.342	0.772	10.770	1.373	163.025	2.838	0.551	0.006
	4	0.4	0.6	74.615	0.780	17.234	1.208	44.312	0.463	10.753	1.269	162.915	1.704	0.606	0.004
	5	0.5	0.5	74.602	0.759	17.445	0.878	44.304	0.451	10.534	0.935	162.885	1.656	0.662	0.004

Table 4. The average values of effective green time (t_{ij}), cycle time (C_i), fitness functions, and corresponding standard deviation in case of unbounded variables for PI_2.

	No.	Alpha	Beta	t1 (avg)	t1 (std)	t2 (avg)	t2 (std)	t3 (avg)	t3 (std)	t4 (avg)	t4 (std)	C (avg)	C (std)	fval (avg)	fval (std)
PI_2	1	0.1	0.9	74.594	1.205	17.191	1.427	44.300	0.716	10.784	1.846	162.869	2.632	6.321	0.188
	2	0.2	0.8	74.659	1.245	17.006	1.219	44.338	0.739	11.006	1.606	163.010	2.718	11.749	0.378
	3	0.3	0.7	74.701	1.331	17.184	1.485	44.363	0.790	10.854	2.053	163.102	2.906	17.186	0.603
	4	0.4	0.6	74.499	0.566	17.304	1.241	44.243	0.336	10.614	1.292	162.660	1.235	22.488	0.330
	5	0.5	0.5	74.914	1.451	17.260	1.089	44.489	0.862	10.903	1.608	163.567	3.168	28.191	1.085

Figure 4, tables 3, and 4 show that the optimal values of effective green time and cycle time are consistent with the four phases of the signal timing diagram of the Taiwan Boulevard - Huichung road intersection after 50 EGA implementations. In addition, the standard deviation values for the mean of t_{ij} and C_i are also better than the standard deviation values for the case of unbounded variables. The fitness functions reach the minimum values when alpha (α) =0.1 and beta (β) = 0.9 for both established fitness functions (PI_1 and PI_2) and this result will be used to compare with the traditional optimization method which is the Webster method and the The existing configuration of the traffic signal timing plan of the Taiwan Boulevard-Huichung intersection.

Current traffic signal timing plans (CP), Optimum Cycle length by Webster formula, and optimal traffic signal timing of PI_1 and PI_2

Table 5. Effective comparisons.

Parameter	Phase	Webster	CP	PI1	Changed by	PI2	Changed by
Phase (s)	T1	28.430	86.000	74.708	-11.292	74.594	-11.406
	T2	9.000	31.000	17.278	-13.722	17.191	-13.809
	T3	24.015	31.000	44.367	13.367	44.300	13.300
	T4	3.954	16.000	10.764	-5.236	10.784	-5.216
Cycle length (s)	C	65.399	180.000	163.118	-16.882	162.869	-17.131
Average Vehicle Delay (s)	AD	27.847	51.648	48.641	-3.007	48.591	-3.057
Emission (g/pcu.h)	E	4787.961	7212.110	6905.864	-306.246	6900.759	-311.351

Table 5 presents that the optimal value of effective green time and cycle time according to Webster's traditional method is the most effective. However, after testing the above results into the traffic simulation model and the actual test, it was found that: the time allocated for the 4th phase of about 4(s) is not enough for the vehicles to pass the signalized intersection. The duration time for the 3rd phase about 24(s) is not enough for pedestrians to cross Taiwan Boulevard safely. Therefore, it is necessary to have a better timing plan to optimize the green light time.

Following the results in Table 5, it is found that the optimal value of effective green time and cycle time for both fitness functions PI_1 and PI_2 after 50 runs of the EGA doesn't have a significant difference. After comparing with the the existing configuration of the traffic signal timing plan of the Taiwan Boulevard- Huichung road intersection, it was found that the result of the PI_2 fitness function is slightly better than the PI_1 fitness function. This proves that it is not necessary to use too many component objective functions to establish the fitness function in the calculation and optimization of the current traffic signal system of an intersection as many studies have shown [25-27]. And the selection of weights to optimize for the normalized fitness function is reasonable in the calculation process.

4. CONCLUSION

The study presented a creating of versatile approach to structuring a model, which providing a fitness function that can reduce traffic average delay and emission simultaneously, allows for adaptability and customization based on different requirements and scenarios by normalizing multiple objectives to ensure compatibility and balance among them based on the optimal traffic signal plan at a signalized intersection, along with different weights. The enhanced GA method demonstrated its effectiveness in solving the a problem involving the optimization of multiple objectives simultaneously, where the aim is to find the best possible solutions that achieve a trade-off between these objectives by limiting the feasible regions of the decision variables and reducing the computational time.

The results showed that the enhanced GA approach outperformed the traditional method in this case study. The empirical analysis revealed the suitability and efficacy of the proposed model formulation for solving challenging or intricate problems that involve various interrelated factors, making them difficult to solve or analyze of traffic the process of optimizing the operations and performance of signalized intersections to improve traffic flow efficiency and overall intersection performance considering the diverse constraints related to phases and schemes when optimizing signalized intersections.

In order to further augment the effectiveness and capabilities of the model, future research could explore the application of various categories of intersections and traffic flow data from different sources.

Overall, the study contributes to the advancement of traffic engineering and programming by proposing an effective and flexible approach to enhance the efficiency and performance of signal timing plans at intersections.

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