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OPTIMAL TRAFFIC SIGNAL TIMING USING GENETIC ALGORITHM CONSIDERING THE VEHICLE EMISSION ISSUE FOR A COMPLEX URBAN ROAD INTERSECTION

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ABSTRACT

Urban growth causes various problems that include the difficulty of managing urban waste, stress on the infrastructure, the pressure of urban traffic networks, and pollution of air quality in the city. Governments of many countries in the world have to pay more attention to optimize the traffic control system as well as to reduce the exhausting emission of traffic networks in urban areas. Particularly, the congested intersection has been the first concern in the traffic network where causes vehicle delays, traffic jams, and excessive fuel consumption. Few researchers attempted to minimize the traffic delays, time loss and queue lengths at a particular intersection. However, those results did not mention the minimization of vehicle emissions at the intersection. On the other hand, several pieces of research suggested the integration of vehicle exhausted emission function in the researched model. Nevertheless, those mentioned models should be enriched by different cases based on real traffic demand. This study aims to generate the comprehensive performance index model that integrates traffic signal optimization and minimizing vehicle exhausted emission for a particular complex intersection in Taichung city Taiwan by Genetic Algorithm. The suggested model has been generated by considering the constraint problems in traffic signal control, optimizing the traffic signal timing, and reducing the fuel consumption at the intersection.

KEYWORDS: Traffic control, Optimal traffic signal timing, Genetic Algorithm, Fuel consumption, Vehicle exhausted emission.

I. INTRODUCTION

The traffic control systems play an important role in the traffic networks that satisfies the main issues of efficiency and safety factors in transportation. In order to manage traffic networks efficiently, urban traffic networks are typically divided into a few subs-traffic networks,[1] or enhanced the capability of the traffic control system by finding the optimal traffic signal timing schemes at a complex urban intersection. According to the minimization of traffic delays and time loss at the congested intersection, several researchers have attempted to establish reliable models that handle the traffic jams at complex large- scale intersections. Wang Ping et al,[2] suggested applying the Genetic Algorithm (GA) to optimize cycle length and effective green times after generating the average delay function from real traffic demand. Halina Kwasnicka and Michal Stanek,[3] supposed that the optimal values of timing plans should be calculated by minimizing time losses and maximizing the average vehicle speed at the intersection. Jianhua Guo et al,[4] has considered three core-factors including green times, cycle length, an offset to derived optimal signal timing plans. However, the consideration of vehicle emissions has been ignored for the isolated intersections or traffic networks in the mentioned researchers above. Nowadays, transportation between urban areas requires not only traffic efficiency and traffic safety but also assesses the impact of vehicle emissions on the city environment. It leads to several researchers developed their own models to deal with the optimization traffic timing plans as well as minimize the fuel consumption or vehicle exhausted emissions at particular intersections,[5-10] Therefore, the suggested models have been generated by combining various objectives which are average delays, traffic capacity, number of stops and vehicle emission functions. Although, these ultimate models could handle their empirical data after normalization of those mentioned functions, however, the weights of those functions should be estimated to support traffic engineers, decision-makers, or the city governments to find the suitable traffic signal timing plans. Hence, this study sets one's sight on providing the complete model to tackle the optimization issue in traffic management, minimizing the vehicle emissions, and analyzing the impact of the weight of sub-functions on the final function.

II. Optimal Traffic Signal Timing Model Based On Vehicle Exhausted Emission

Table 1: Notations and definitions.

AD_I	**Average vehicle delay of the complex isolated intersection in seconds**
C	Cycle time
t_{ij}	Effective green times for phase i lane-group j
X_{ij}	The ratio of traffic flow to capacity of lane group j in phase i
T	Analysis period equals 15 minutes or 0,25 hour in this case study
k	Incremental delay factor
I	Upstream filtering adjustment factor equals 1.0 for a particular isolated intersection
v_{ij}	The traffic flow rate of lane group j for phase i
L	Total loss-time
$\sum_i (\frac{v}{s})_{ci}$	The sum of the critical lane group flow ratio
X_c	Critical v/c ratio for the intersection that defined by the traffic volume (v) and traffic Capacity (c) at the intersection.
y_i	The ratio of actual traffic volume and saturated traffic volume (S_{ij})
H_i	The total number of stops at the signalized intersection
C_{ap}	Traffic capacity
E_I	The total vehicle emission at the intersection
q_j	Traffic arrival, traffic flow
L_j	The length of the entrance section of the intersection
d_j	Average delay of the vehicle in lane group j
EF^{PCU}_{ij}	The standard car unit emission factor (g/(pcu.h)
EFI^{PCU}_{ij}	The Standard Car Unit Idling Emission Factor (g/(pcu.km)
D	The distance of the crosswalk
S_p	Walking speed of pedestrians
W_E	The width of the crosswalk (ft)
N_{ped}	The number of pedestrians crossing during the green interval
E_I	Total vehicle exhausted emission
C_{min}	The minimum value of cycle length (s)
C_{max}	The maximum value of cycle length in (s)
$t_{ij,\ min}$	The minimum value of effective green time
$t_{ij,max}$	The maximum value of effective green time
S_{ij}	Saturation flow rate

II.1. Establishing model formulation

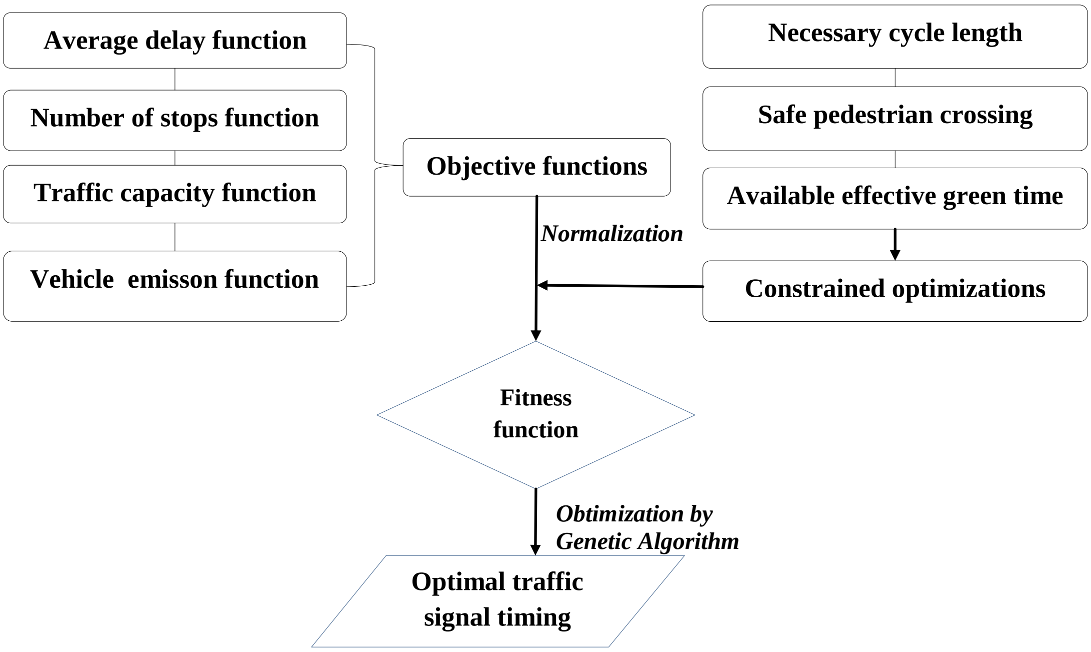


Fig. 1: Model formulation.

II.2. Normalization of objective functions

As mentioned above, the considering of the integrated optimization issues will be generated in this study by establishing a fitness function based on various performance index functions average delay function, the number of stops function, capacity function, and vehicle emission. Note that the output variables of the suggested model are cycle length C and effective green times t_{ij} for timing control scheme at the intersection.

The average delay function.[11]

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

The number of stops function.[8,12]

$$\mathbf{H_I}=0.9\sum_{i=1}^{n}q_i\cdot\left(\frac{1-{t_{ij}}/{C}}{1-y_i}\right) \quad \textbf{(2)}$$

The capacity function.[13,14]

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

The vehicle exhausted emission.[5,8]

$$E_I= \sum_{j=1}^{n}\left(EF_{ij}^{PCU}.q_j.L_j+\frac{1}{3600}.EFI_{ij}^{PCU}.q_j.d_j\right) \quad (4)$$

In order to provide a comprehensive model formulation, multiple objectives have been normalized by the minimum conditions of average delay function, the number of stops function, vehicle emission function and maximum condition of traffic capacity function, as the following expression:

$$\begin{cases} F_1 = \min AD_I \\ F_2 = \min H_I \\ F_3 = \min(-C_{ap}) \\ F_4 = \min E_I \end{cases} \quad (5)$$

Equivalent to:

$$\text{Min PI}= \min\left(\alpha\left(\sum_{i=1}^{n}\frac{AD_I}{AD_0}+\sum_{i=1}^{n}\frac{H_I}{H_0}+\left(\sum_{i=1}^{n}-\frac{C_{ap}}{C_{ap0}}\right)\right)+\beta\sum_{i=1}^{n}\frac{E_I}{E_0}\right) \quad (6)$$

Where: PI is the performance index function or fitness function. AD_0, H_o, C_{ap0}, and E_0 are the initial values of average delay, number of stops, traffic capacity and vehicle emissions respectively. The weights α and β describe different scenarios that support decision-makers or planners to consider the benefits between traffic efficiencies and vehicle exhausted emissions at a particular intersection. In the case of α greater than β, decision-makers pay more attention to traffic efficiencies and vice versa.

II.3. Definition of constrained optimizations

As a part of the model formulation, constraints limit the infeasible solutions to search the global optimization values. Thus, approaching suitable constraint conditions could support the mathematical model to find the optimum results much faster. Based on the considering of making traffic much safer and more efficient, the traffic signal timing schemes need to provide enough time for vehicles pass-through the intersection without stopping and ensure the smooth operation of traffic coordination as well as traffic networks. The conditions of necessary cycle length, safe pedestrian crossing, and available effective green times have been defined. Particularly, limitation values of cycle length and effective green times in the traffic control system at the intersection could be found by,[15,17] as the following expression:

$$\left.\begin{array}{l} C_{min} \le C \le C_{max} \\ t_{ij,min} \le t_{ij} \le t_{ij,max} \end{array}\right\} \quad (7)$$

Subject to:

$$C_{min} = \frac{L \times X_c}{X_c - \sum_i \left(\frac{v}{s}\right)_{ci}} \quad (8)$$

$$C_{max} = 180\ (s) \quad (9)$$

$$t_{ij,min} = 3.2 + \frac{D}{S_p} + 0.27\ N_{ped}\ , \ \text{for } W_E \le 10ft \quad (10)$$

$$t_{ij,min} = 3.2 + \frac{D}{S_p} + 0.27\frac{N_{ped}}{W_E}\ , \ \text{for } W_E \ge 10ft \quad (11)$$

$$t_{ij} \le C_{max} - L - (n-1)\frac{C_{min}}{0.95}\left(\frac{v}{s}\right)_{ci} \quad (12)$$

$$\sum_{i=1}^{n} t_{ij} = C - L \quad (13)$$

II.4. Genetic algorithm operation

A wide variety of research demonstrated that the advantages of GA in optimization fields are overwhelming the current traditional method based on optimization technique, the process of natural evolution, and global search heuristic algorithm. Additionally, principal components of GA are chromosome design, fitness function establishment, and appropriateness of GA's operators.

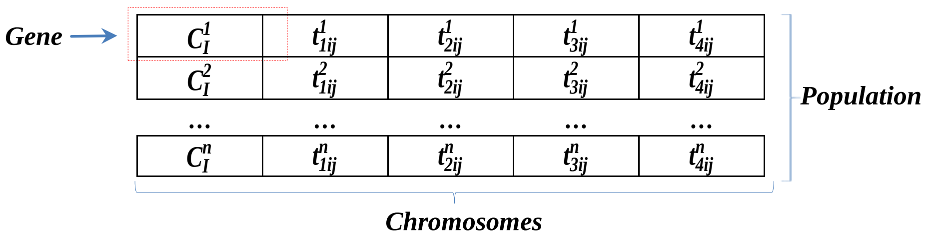


Fig. 2: Chromosome design for four-phase signalized intersection.

In the case of optimistic traffic timing plans at the particular intersection, the timing plan ingredients of a signalized intersection have been coded by an individual chromosome. In this study, we suppose a single chromosome designed cycle time (C_I) and effective green times (t_{ij}).

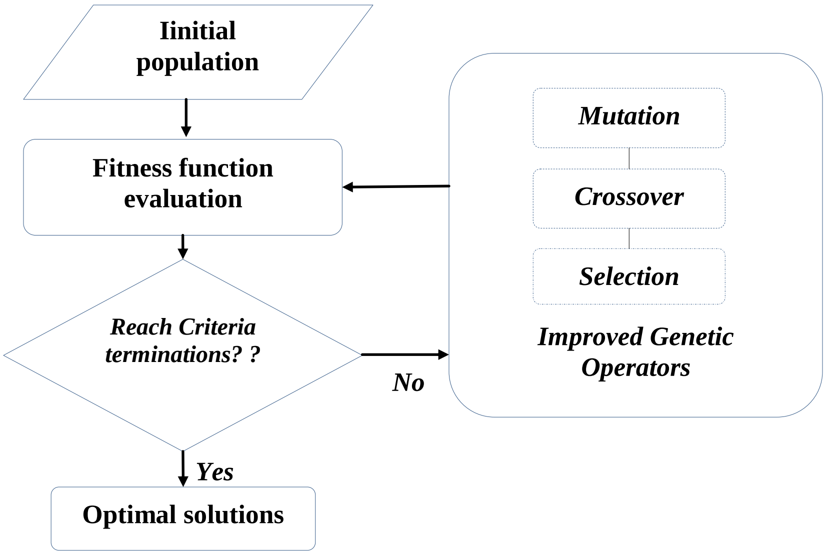


Fig. 3: The basic process of Genetic Algorithm.

The process of GA has been performed by the following steps:

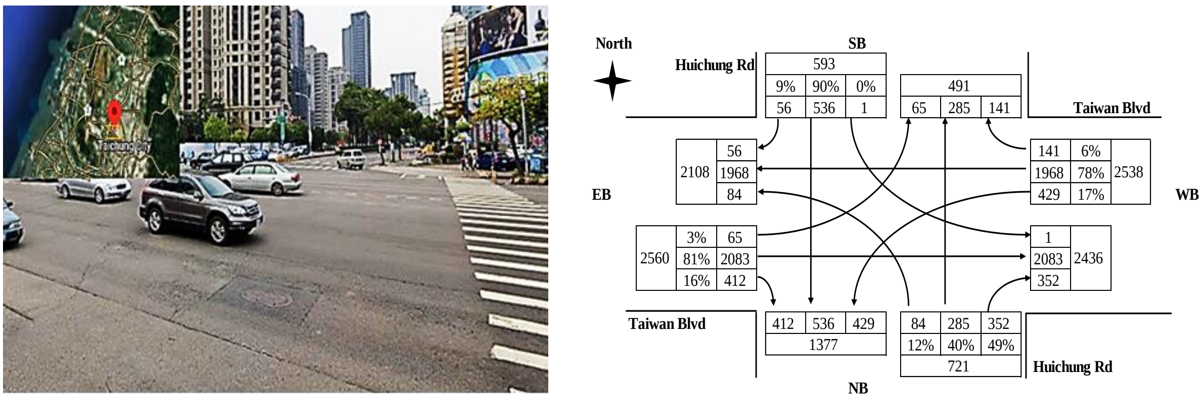
i) The initial population has been generated based on encoding the design of chromosomes. Typically, there are two encoding methods which are binary coding and number coding. In this paper, the suggested model utilized the real number coding due to the advantages of its.

ii) According to the requirements of the fitness function that established in the previous section. GA's process directly evaluates the criteria terminations until meeting the criteria terminations to search the globally optimum values.

iii) In the case of failure to achieve terminate conditions, the GA improves its capability based on the evolutionary process by enhancing the GA's operators (selection, crossover, and mutation) to re-evaluate the fitness function and find the optimization results.

III. CASE STUDY

III.1. Data collection



(a) (b)

Fig. 4: Taiwan Boulevard- Huichung Road intersection. (a) The intersection location. (b) Traffic arrival flow rate of this intersection in rush hour from 7 am to 8 am.

Taichung City is located in the middle of Taiwan. It is well-known as a transshipment location between the North and the South of Taiwan. In recent years, the city government prioritizes the development of long-term infrastructure in public transport to encourage citizens to use its service facilities.[16] The Mass Rabit Transit system(MRT) is being built and planned. Thus, the most popular type of public transport in Taichung city is bus services using road traffic network.

As a result of urban development, citizens tend to use private vehicles when the public transport system is under construction. The rates of using private cars and private motorbikes in Taichung city are still high. Therefore, the road transport system is being congested during rush hours at some particular intersection in major roads in Taichung city.

In this study, the real traffic data has been collected at Taiwan Boulevard- Huichung Road intersection located in Taiwan Boulevard, one of the major roads in Taichung city with high-density traffic. The traffic situation of the mentioned intersection is really complicated in peak periods from 7 am to 8 am and from 5 pm to 6 pm when residents out of working hours every single day. Hence, the optimal traffic signal timing scheme at this intersection is needed. ***Fig.4*** shows the location of collected data intersection, and the traffic- flow rate of Taiwan Boulevard- Huichung road intersection in PCE (Passenger Car Equivalent) from 7 am to 8 am morning. EB, WB, NB, and SB stand for the Eastbound, the Westbound, the Northbound, and the Southbound of the intersection respectively.

III.2. Data analysis and results

According to the traffic flow data of Taiwan Boulevard- Huichung road intersection, the fitness function has been established by following the formulations from (1) to (6). Besides, constrained conditions were created based on the traffic geometry data and real traffic flow data of the intersection by the indicated formulas from (7) to (13). On the other hand, several scenarios are predetermined to test the effectiveness of the model formulation:

i) $\alpha = 0.4 < \beta = 0.6$ to consider that vehicle emission is more important than traffic efficiency.

ii) b) $\alpha = \beta = 0.5$ to consider the effect of both factors equally.

iii) c) $\alpha = 0.6 > \beta = 0.4$ to consider traffic efficiency is more important than vehicle emission.

An appropriate process of formulated the Genetic Algorithm might approach the global optimization value of the fitness function. Precisely, the effectiveness of the Genetic Algorithm depends on the suitable GA's operators (selection, mutation, and crossover), population size, techniques use of reproduction and stopping criteria.[3,17-20] In this study, the critical mentioned factors of GA's process has been designed by the following table:

Table 2: Critical factors of formulated GA.

Factors	Values	Techniques use
Population size	200	-
Selection	-	Uniform
Reproduction	0.05 x Population Size	Elite count
Mutation probability	0.1	Adaptive feasible
Crossover probability	0.5	Intermediate

RESULTS

Table 3: Optimal results of different scenarios.

Factors	T1 (s)	T2 (s)	T3 (s)	T4 (s)	C (s)	Average-delay (s)	Emission (g/h)	Number of stops (Stops/h)	Capacity (Pcu/h)
Initial values	***86***	***31***	***31***	***16***	***180***	***51.65***	***7212.11***	***4830.05***	***12698.33***
α=0.4; β= 0.6	75	11	45	8	155	45.63	6599.41	4735.09	12883.23
α= 0.5; β= 0.5	78	11	44	11	160	46.61	6699.49	4728.81	12920.00
α=0.6; β= 0.4	81	18	44	5	164	46.88	6726.03	4675.63	12998.78

Table 4: The comparison results between initial values and calculated values of the mentioned model (Initial value = 100%).

Factors	α=0.4; β= 0.6	α= 0.5; β= 0.5	α=0.6; β= 0.4
Average delay	88.%	90.3 %	90.8 %
Emissions	91.5 %	92.9 %	93.3 %
Number of stops	98.0 %	97.9 %	96.8 %
Capacity	101.5 %	101.7 %	102.4 %

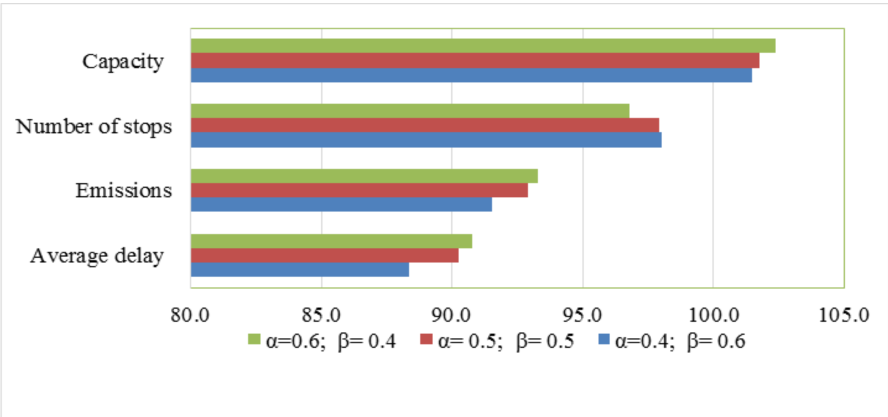


Fig. 5: Objective functions comparison between initial values and calculated values (initial value =100%).

IV. CONCLUSIONS AND REMARKS

The results in Table.3 above show that the effective green times and cycle lengths of the suggested model are shorter than the existing effective green time and cycle length for the four-phased intersection in all supposed scenarios. Moreover, the values of objective functions are better than the original function values for three scenarios. It demonstrates the effectiveness of model formulation to find the optimization values of the traffic timing plan at the intersection to reduce the emission as well as enhance the traffic efficiency.

In order to compare different scenarios, it's obvious to see in Table.4 and Fig.5 that the weight and function value of vehicle exhausted emission function have a positive correlation. It proves that the model formulation could support planners to decrease vehicle emissions by changing the weight of the formulated function (PI). Additionally, three coefficients that describe the traffic efficiency (traffic capacity, number of stops and average delay), the values of traffic capacities in various scenarios are easy to recognize the changes by changing the weight α, while the remaining parameters have slight fluctuations.

The optimization results based on supposed GA's process illustrate the consequences and suitability of GA to tackle complex problems of optimal traffic signal timing at the intersection with various constraints of phases and schemes. To enhance the effectiveness and capability of suggested model formulation, different types of intersections with various traffic flow data will be utilized for future work.

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