NEW HIGHWAY GEOMETRIC DESIGN METHODS FOR MINIMIZING VEHICULAR FUEL CONSUMPTION AND IMPROVING SAFETY

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Abstract— Traffic signal control is an integral component of an intelligent transportation system (ITS) that play a vital role in alleviating traffic congestion. Poor traffic management and inefficient operations at signalized intersections cause numerous problems as excessive vehicle delays, increased fuel consumption, and vehicular emissions. Operational performance at signalized intersections could be significantly enhanced by optimizing phasing and signal timing plans using intelligent traffic control methods. Previous studies in this regard have mostly focused on lane-based homogenous traffic conditions. However, traffic patterns are usually non-linear and highly stochastic, particularly during rush hours, which limits the adoption of such methods. Hence, this study aims to develop metaheuristic-based methods for intelligent traffic control at isolated signalized intersections, in the city of Dhahran, Saudi Arabia. Genetic algorithm (GA) and differential evolution (DE) were employed to enhance the intersection's level of service (LOS) by optimizing the signal timings plan. Average vehicle delay through the intersection was selected as the primary performance index and algorithms objective function. The study results indicated that both GA and DE produced a systematic signal timings plan and significantly reduced travel time delay ranging from 15 to 35% compared to existing conditions. Although DE converged much faster to the objective function, GA outperforms DE in terms of solution quality i.e., minimum vehicle delay.

1. INTRODUCTION

India has become a middle-income country with per capita income of Rs 10,534 in 2018-19. And this economic growth has increased with affordability of people thus making them to go with more comfortable and more luxurious travel modes all the time. Coming to Vijayawada the new Capital of Andhra Pradesh city attracts about 1.5 million floating population on any working day. The total population in the city increases to more than 2 million during the daytime, with the addition of the resident population of the city. It was found that about 50% of the commuting population arrives to the city for employment or to engage in commercial activities and or to attend educational institutions. The rest comes to the city for various other purposes. Commuting population uses various transportation modes to enter the city. According to estimates, about 15,000 buses operated by both public and private sectors bring 2,00,000 passengers daily to the city. Another 3, 00,000 commuters use about 90,000 private vehicles. The number of commuters using the railway to enter the city is estimated to be around 165,000. Both the commuters and the number of vehicles entering the city are increasing year by year. At the same time the residential population and the ownership of vehicles within the city limits also experience an unprecedented growth. Number of vehicles that entering to the city from nine entry points on working days have been estimated to be around 275,000, and this is in addition to the use of vehicles of the residents in the city. Traffic problem has been aggravated by the concentration of all forms economic, commercial, and administrative functions in the city.

Furthermore, Vijayawada is the largest city in the AP and, therefore, it attracts people for its commercial and political significance and as it offers better facilities in health, education etc. than any other city in the country. The combination of all these aspects results in a greater attraction of the city for people from the rest of the country thus aggravating the transport problem in the city of Vijayawada.

Transportation problem that currently experienced by the Vijayawada city is reflected in the increasing traffic congestion. A few years ago, the traffic congestion was largely limited to the Vijayawada Municipal Corporation (VMC) boundary, but now it has spread to the entire area lasting sometimes most of the peak period. Heavy traffic congestion prevails during school- opening hours especially between 7:30 am – 8:30 am followed by office traffic between 8:00 am and 9:00 am. In the afternoons and evenings, the same sort of traffic congestion is witnessed between 1:30 pm – 2:30 pm and between 5:00 pm – 8:00 pm for the same reasons. The main implication of traffic congestion is that it causes higher running costs to the owners of vehicles resulting a considerable loss to the national economy. This problem may get worse in the immediate future since the road networks are severely inadequate to meet the current demand.

The number of vehicles in the city is not the only the factor contributing to congestion. Poor public transport facilities, shortage of parking areas, parking of heavy vehicles on busy roads during normal working hours, and inadequate facilities for pedestrians also contribute equally to the problem of congestion. As a consequence, the average vehicle speed within most parts of the city has reduced to around 10 kilometres per hour during the day. When the average speed decreases, it leads to longer travel times, causing an economic loss as a result of high fuel consumption and rise in pollution levels. Generally, there are many adverse effects due to traffic congestion, such as:

• Delays; which may result in late arrival for employment, meetings, and education, resulting lost of business, disciplinary action, or other personal losses;
• Inability to predict travel time accurately, leading to the allocation of more time to travel by drivers which can be used on more productive manner;
• Increased air pollution and carbon dioxide emissions due to idling engines; and
• Wear and tear on vehicles as a result of idling in traffic and frequent acceleration and braking, leading to more frequent repairs and replacements.

SIGNIFICANCE OF WORK:

As mentioned earlier increasing the number of vehicles in the road becomes one of the key reasons for increasing the traffic congestion in Vijayawada city and its suburbs. As per Vijayawada Metro Rail Detailed Project Report (DPR) prepared in 2015, the total number of vehicles registered in the district is 87,513. There are 9,700 goods vehicles, 1,598 taxi cars, 25,432 private cars, 42,300 two wheelers, 8,765 auto rickshaws and 1,674 buses. Diesel consumption in the country rose to 83.5 million tonnes while petrol consumption rose to 28.3 million tonnes during 2018-19. It was noted that transportation sector is the dominant user of liquid fuels with 70 percent of oil used in the world during year 2011. India uses 7% of its total energy for transport sector, compared to 21% in Srilanka, 16% in Thailand and 19% in Malaysia. All of these factors effects nationally a considerable amount of financial costs. Given the projected growth in the demand for transport facilities in the coming decade, upgrading and expanding the transport sector must receive urgent priority. Therefore, it is good to study about the amount of fuel wastage due to idling at signalized intersections.

The aim of this study was to assess the idling profile of vehicles and to provide an estimation of fuel loss during idling of vehicles at the signalized intersections within VMC.

2. LITERATURE SURVEY

Aleksandar et al. conducted a study on optimizing traffic control to reduce fuel consumption and observed that if a vehicle was completely stopped and the engine was idling, it consumed less amount of fuel than the vehicle was moving at 40 mph. It was found that even though vehicle's fuel per second consumption was lower when idling, fuel per mile consumption was higher.

Ashrafur et al. investigated the impact of idling on fuel consumption and available idle-reduction technologies. It was found that vehicle's engine consumed more fuel when idling duration exceeds 10 seconds, compared to the fuel usage when restarting it. Also, it was pointed out that fuel consumed by idling engine for just 10 minutes was equal to the amount of fuel required for 5 miles of driving.

Parida and Gangopadhyay estimated the fuel loss during idling of vehicles at signalized intersections in Delhi. The traffic data were generated through field surveys and fuel consumption data were obtained using idling flow measurement system comprising FP 214OH flow detector and DF 210B flow meter. The average delay per vehicle was determined by conducting speed and delay surveys at each of the intersection arm separately. Vehicular delays during different hours of the day were calculated by multiplying the average hourly classified traffic flow with the corresponding average delay. The economic loss of fuel was estimated by multiplying fuel loss with the prevailing cost of fuel. Improper city planning and development were the major reasons for urban transportation problems. The separation of work places and residential areas resulted in enhanced trip lengths and increased travel time on roads. Which had a direct impact on fuel usage and emission. It was observed that after the implementation of remedial measures, a total of 67.78 percent of fuel savings and a 71.12 percent savings in the economic loss shall be acquired.

Sekhara et al. estimated the delay and fuel loss during idling of vehicles at signalized intersection in Ahmedabad. A simulation model was developed to study the urban traffic and highway operations. Classified traffic volume with turning surveys were carried out at intersections to assess the existing traffic volume and travel speed at the selected intersections. A test car attached with Global Positioning System (GPS) based equipment was used to identify the existing speed and delay. Fuel consumption test at idling flow measurement system comprising detectors and flow meters were used to obtain the fuel consumption data. The study was proposed construction of flyovers along the drive-in roads to reduce the delay and fuel wastage. It was found that on an average 74% of idling delay can be reduced with the implementation of flyovers on the selected intersections.

3. STUDY AREA AND DATA DESCRIPTION

With a view to achieve the aim of this study, signalized intersection with medium traffic volume was selected; the Benz Circle. Figures 1 shows the arm distribution of the selected intersection. The intersections have been categorized as low, medium and high with the criteria; low volume intersection < 75,000 vehicles per day, medium volume intersection 75,000 - 100,000 vehicles per day and high volume intersection > 100,000 vehicles per day. Based on the total number of vehicles presence at intersections, Benz Circle can be identified as medium volume signalized intersections.

Figure Investigated intersection Benz Circle

As shown in Figure, Benz Circle is a four-arm signalized intersection formed by meeting NH16, Auto Nagar Road, Main Road. This is one of the busiest signalized intersection in Vijayawada. Benz Circle intersection consists of four signal phases. The data required to estimate the fuel loss occurring at the intersections as follows:

The word "optimization" came from the same root "optimal" which indicate best. Thus, optimization may be defined as the process of achieving the best possible solution under given constraints. A typical optimization problem can be mathematically formulated as:

$$minimize/maximize\, f(x)\, subject\ to \begin{cases} gi(x) \le 0;\ i = 1,2,3 \ldots n \\ h\ i(x) = 0\ ;\ i = 1,2,3 \ldots n \end{cases}$$

Where $f(x)$ is the output/objective function to be optimized, $g_i(x)$ denote set of inequality constraints, $h_i(x)$ represent equality constraints. Constraints are limits within which the variables may be varied. The variables x_1, x_2, x_3 , x_n € R^n (solution space) are the control or decision variables. By convention, optimization means a minimization problem, however it can also be designed as maximization problem by negating the sign of objective function. Optimization problem given above could be considered as decision problem that involves finding the best vector x of all control variables from the solution space.

In this study GA and DE optimization techniques were employed to minimize the average vehicle delay (objective function) through isolated signalized intersections as a function of several input variables (i.e., traffic demand, existing phasing scheme, g/C ratio, saturation flow etc.), and constraints conditions (cycle length and individual green splits). Green splits in each phase (g_1, g_2, g_3, *and* g_4) were decision or control variables. The primary objective was to minimize average vehicle delay in response to approaching traffic demand by selecting best possible combinations of signal timings plan. GA and DE optimization program for current study were developed on MATLAB interface (version R2018b). The following sections provide a brief summary of architecture and working principle of both algorithms, step-wise respective algorithms procedures for current optimization problem, and constraints conditions for obtaining optimized objective function.

4. RESULTS AND DISCUSSIONS

Convergence of GA and DE

Figure plots convergence to minimum objective function for GA and DE against number of generation/iterations. The objective function represents the minimum average vehicle delay (given in units of s/veh.) through the intersection. To comply with the central limit theorem, the convergence curves shown in Figure indicate the mean rating of the best candidate solutions in the population at each iteration for 30 executions set for both algorithms. Analysing the convergence pattern from the plots, it is worth to note that both the curves converge rapidly to smaller and smaller values of the objective function. Both the curves become flat onwards after the objective function reaches a steady value as the number of iterations is increased. It can be observed from the plots that DE converges much faster than GA. However, GA solution quality from GA is slightly better as both the algorithms ultimately proceed to complete the fixed number of iterations. The fact that DE outperforms GA in terms of convergence to fitness function is consistent with several previous studies. For Intersection-I (shown in Figure a), DE graph converged to objective function value of 78.6 at about 80 population generations, while GA reached a minimum objective function value of 64.3 at nearly 150 iterations. Similarly, for Intersection-II (Figure 5b), it may be noted that again DE convergence is much faster (60 population generations) compared to GA (200 population generations) to the minimum objective function. The minimum function fitness value for this case was 55.9 using GA and 72.8 with DE. Further, the MATLAB program/code execution took an average between 0.25 to 0.40 s and 0.8 to 1 s for DE and GA, respectively.

Optimization of Cycle Length and Green Splits

Table presents optimized signal cycle lengths and corresponding green splits for each bound. Green splits were the input decision variables for both algorithms and were programmed and controlled to have values between 8 to 45 s, as recommended by a previous study. The objective was to select the best possible combination of green splits in response approaching traffic volume to minimize the objective function i.e., average vehicle delay at the intersection. It may be noted from Table that the optimized green splits distribution from both GA and DE are intuitively based on the proportion of traffic volume from the respective approach. Intersection clearance interval consisting of “yellow and all red” was the same from existing conditions to ensure safety and smooth operations at intersections. There was a 15 to 42% reduction in green splits from an existing pashing scheme using GA for both intersections, whereas DE yielded percent difference ranging between 26 to 52%. Although percent decrease in individual green splits was more pronounced from DE, overall, reduction in average vehicle delay was less compared to GA.

Table Optimized cycle lengths and green splits by GA and DE.

Phase Direction	Intersection	North Bound (NB)	South Bound (SB)	West Bound (WB)	East Bound (EB)	Clearance Interval All Bounds	Intersection Cycle Length
Splits		Green split I (% Difference)	Green split II (% Difference)	Green split III (% Difference)	Green split IV (% Difference)	Yellow + All Red 4 * (3 + 2)	-
Genetic Algorithm	1	12 (20)	41 (15)	45 (33.33)	30 (40)	20	148
Differential Evolution	1	11 (26.67)	32 (46.67)	37 (47.14)	25 (50)	20	125
Genetic Algorithm	2	10 (33.33)	16 (36)	27 (40)	32 (41.82)	20	105
Differential Evolution	2	10 (33.33)	13 (52)	20 (44.44)	29 (52.72)	20	92

Note: Values in parenthesis indicate percent difference from existing conditions.

Delay Comparison with Existing Condition

Figure provides a comparison of average vehicle delay for existing conditions as well as the optimum delay estimates obtained from GA and DE at both intersections. Intersection-I had an existing cycle length of hefty 220 s with corresponding average vehicle delay through intersection being 102.5 s/veh. Signal control at this intersection is very poorly designed, and during rush hours, vehicles have to wait in long queues waiting to pass the intersection. Unless some preventive measures are adopted, in the near future, it is likely that the current prevailing level of service (LOS) D and E operating conditions could rapidly turn to breakdown LOS conditions, particularly during peak periods. This will cause chaos in the vicinity of the intersection. Optimization using GA estimated a cycle length of 148, having a reasonable average delay value of 64.3 s. While DE yielded an optimized signal cycle length of 125 s for Intersection-I with slightly high average vehicle delay value of about 78 s. Intersection-II had slightly better operating conditions having an existing cycle length of 160 s and associated delay of 86.5 s/veh. Again, reduction in optimized cycle length from DE (92 s) was more pronounced compared to GA (105 s). However, GA was found more efficient and robust, yielding significantly low estimates for optimum/minimum delay (55.9 s/veh.) than DE (72.8 s/veh.) algorithm. Table 5 presents the percentage reduction in cycle length and average vehicle delay for GA and DE algorithms. Optimized cycle length from GA was approximately 32% of existing cycle length at Intersection-I and about 34% of original cycle length at Intersection-II. DE, on the other hand, provided a cycle length reduction of a little over 40% for both intersections. Optimized cycle length from GA was approximately 32% of existing cycle length at Intersection-I and about 34% of original cycle length at Intersection-II. DE, on the other hand, provided a cycle length reduction of a little over 40% for both intersections. Comparing the percent reduction in average vehicle delay, GA was capable of achieving a decrease of approximately 37% and 35% at Intersection-I and Intersection-II, respectively. While using DE, average vehicle delay was reduced by 23% at Intersection-I, and around 16% at Intersection-II.

APPORCHING DAILY TRAFFIC OF THE EACH INTERSECTION

Intersection	Traffic Approaching From	Traffic Approaching	Total Traffic
Benz Circle	NH16 Towards	29,356	97,137
	NH16 Towards	23,673	
	Auto Nagar Road	26,430	
	Railway Station Road	17,678	
NTR Circle	Eenadu Road	29,498	93,182
	Autonagar Road	14,616	
	Nirmala Convent Road	18,395	
	Krishnaveni School Road	30,673	

A. Benz Circle

Based on the data observed, hourly traffic variations in each mode at the intersection are shown in Figure 3. The total traffic composition in the Benz Circle is shown in Table III.

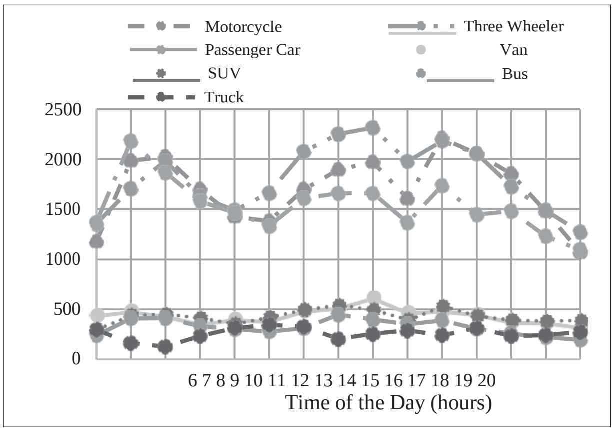

Fig. Hourly traffic variation at Benz Circle

The composition wise observed traffic flows were converted into Equivalent Passenger Car Units (EPCU) multiplied by Passenger Car Unit (PCU) factors of multi-lane roads. It was found that equivalent passenger cars composition was significant at this intersection and was about 27%.

TABLE 5.4. DAILY TRAFFIC COMPOSITION AT BORELLA INTERSECTION

Vehicle type	Motor cycle	Three-Wheeler	Car	Van	SUV	Truck	Bus
EPCU	12,774	21,745	23,079	6,427	6,259	8,690	6,486
%	15	25	27	8	7	10	8

Delays were estimated through field surveys and idling delays observed by drivers at the Borella intersection are shown in Figure 4. The delays experienced by drivers were more than 20 seconds per vehicle for all the approaching arms at the intersection. Delays were as high as 535 seconds per vehicle during peak hours and the highest percentage of idle vehicles were found between 11:00 am to 4:00 pm at

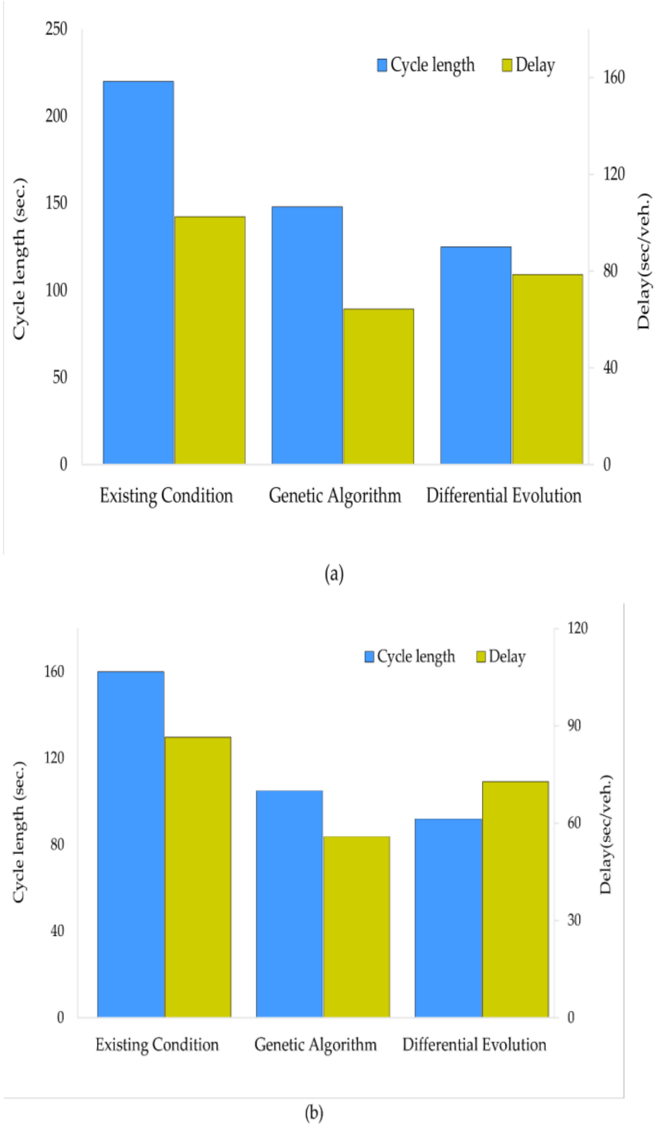

Figure. Comparison of cycle length and average delay: (**a**) Intersection-I; (**b**) Intersection-II.

5. CONCLUSION

This study aimed to optimize delay and achieve intelligent traffic control at isolated signalized intersections through application of meta-heuristic search optimization methods. A critical analysis of existing literature on the specific topic revealed that most of these studies have focused on lane-based homogenous traffic conditions. Engine idling is one of the major problems faced by transportation industry, especially near signalized intersections. The study describes the process of estimating the fuel loss during idling of vehicles at signalized intersections. The study was performed in Colombo, the commercial capital of Sri Lanka. The selected study area consisted with two signalized intersections with medium traffic volumes. The primary data for this research study were approaching traffic volume, idling delay, and idling fuel consumption of vehicles. Since the selected signalized intersections were having huge vehicle flow, CCTV surveillance footages recorded by the Sri Lanka Police were used to obtain the traffic flow data. Two persons, a driver and a GPS recorder were needed to perform the data collection work for the idling delay. The GPS device error range was within one meter for distance measurements. The accuracy of GPS device was considered as very high for the estimation of idling delays since it was used to record the test vehicle positions data at one second time intervals. With the GPS positioning data, idling delays experienced by drivers at the signalized intersections were estimated by plotting distance vs time graphs. The required vehicle idling fuel consumption data were obtained from previous research.

It was found out that on an average fuel worth LKR 196,627.46 and LKR 146,621.04 is wasted daily at Benz Circle, intersections respectively. Some of the important conclusions based on the present study are as follows. It was observed that the present heavy traffic congestion at the signalized intersections was the main reason for huge amount of fuel wastage from the vehicles. Furthermore, it was found that passenger cars were the main mode of transportation of most people and it had the majority of traffic fleet. Also, findings show that idling delay increases when number of lanes at an approaching arm decreases and idling delays experienced by drivers were more than 10 seconds per vehicle for all the approaching arms at the selected signalized intersections.

Some of the remedial measures which can be suggested to reduce vehicular delays and fuel wastage due to idling of vehicles at signalized intersections would be, implementation of vehicle actuated traffic signals, traffic signal synchronization on important routes, optimization of signal cycle timings, provision of adequate road facilities, conduct public awareness program to encourage engine switching off behavior of drivers of the waiting time is more than 15-20 seconds, policy implementation to monitor the engine switching off behavior, improve public transport system, increase vehicle importing taxes and toll charges to reduce the use of private vehicles, construction of flyovers at high volume intersections, encouraging non-motorized traffic modes, and encourage people to use electric and hybrid vehicles. Also, lack of discipline either by the vehicle or by the pedestrians at signalized intersections can create conflicts which may resulting increasing in delay and fuel loss. Therefore, stricter enforcement must be taken to control the observance of lane discipline, jumping of red lights and parking violations, etc. Furthermore, this research would be beneficial for many organizations and agencies who are engage in planning, designing, building, operating, and maintaining transportation systems.

REFERENCES

[1] Worldbank organization, “Sri Lanka Data”, Internet: http://data.worldbank.org/country/sri-lanka., 2016.

[2] D. Edirisinghe, “Managing Traffic Congestion in Colombo and Its Suburbs”, Sri Lanka Institute of Development Administration, 2014.

[3] Department of Motor traffic Sri Lanka. “Statistics: Registartion of Motor Vehicles”, Internet: http://www.motortraffic.gov.lk/web/index.php?option=com_content&view=article&id=84&Itemid=115&lang=en., 2016.

[4] Ceylon Petrolium Corporation, “Ceypetco Annual Report-2013”, Colombo, Sri Lanka: CPSTL., 2013.

[5] T.Y. Liao, R. B. Machemehl, “ Optimal Traffic Signal Strategy for Fuel Consumption and Emissions Control at Signalized Intersections”, Austin, Texas, U.S.A.: *Association for European Transport*, 1992.

[6] A.Stevanovic, J. Stevanovic, K. Zhang, and S. Batterman, “Optimizing Traffic Control to Reduce Fuel Consumption and Vehicular Emissions”, Washington: Transportation Research Board of the National Academics, Washington, 2009.

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