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Application of Embedded System in Designing Optimal Signal Cycle for Minimizing Automobile Emission at Signalized Junctions for Better Environment Management

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ABSTRACT

This research paper deals with the improvisation of philosophy of traffic signal cycle time design based on IRC:93-1993 guidelines, which is based on two fundamental parameters i.e. peak one hour traffic flow and recommended saturation flow values obtained from field observations. Webster method is used in the signal design process assuming homogenous traffic as prevailing in developed countries. volume and saturation flow is converted to PCU values. In India the traffic is heterogeneous and this would result lot of unused green time and due to idling of vehicles leading to fuel wastage causing air pollution. Hence, it is proposed to introduce totally a new concept of signal design based on variable traffic volume and variable saturation flow values for each road separately obtained from field studies. These values are installed in the Embedded System of the signal system. The actual signal cycle time, green time and Red time for prevailing traffic volume and saturation flow values at any given time of the day is calculated based on Program installed in the chip. This signal design concept is innovative in nature and avoids excess unused green time for each signal cycle for the entire signal operation period in a day thus resulting in less emission followed by reduction in air pollution.

Keywords : Delay, traffic volume, saturation flow, optimum signal cycle time, air pollution, Embedded System

I. INTRODUCTION

Bengaluru city has more than 350 signalized junctions. All the signalized junctions have varying road geometrics, variable traffic flow and composition, saturation flow characteristics and pedestrian flow across all roads. Traffic flow varies from morning to night making it difficult for the design of signal cycle time. The variation of traffic volume across any junction is figure and this is observed at all junctions in the entire city. It is common practice that the signals are designed based on IRC: *93-1993* guidelines [1]. This code considers only peak hour traffic volume collected from the field and recommended saturation flow values from the standard tables. This fixed value of both the flow the traffic parameter is used in the design of signal phases for all roads of the junctions. This results in lot of unused green time of the signal phases resulting in ineffective use of green time. As the demand for green time varies with the traffic volume and in effective use of green time followed by long waiting time for all the vehicle at the junction. These further results in wastage of fuel thus increasing in air pollution. This happens at all signalized junctions in Bengaluru, and this may be

overcome by using an alternate method of signal design by considering variable flow parameter in signal design equation each time in a block period of 5 minutes. The data for each cycle is drawn from memory of the chip installed in the signal system and each time in block period of five minutes the relevant equations are used for the calculation of green time. The installed embedded system in the signal unit draws the traffic data from the memory chip board and the actual cycle time required is calculated and apportioned into green time required for each road separately. Then the signal phases allocate the green time in proportion to actual traffic volume and saturation flow for every five minutes increment of time, from the time the signal is on in the morning to night. On an average at each junction about 50% of green time is saved in a day for a block period of 5 minutes.

II. Literature Review

Extensive research has been carried out by many Researchers in determining the loss of time or delay at signalized junctions and emissions during waiting for green phase. The reduction in operating speed or waiting at signalized junction is found to increase the fuel consumption, standing delays to vehicles and road users followed by atmospheric air pollution. Following is the brief account of the different types of Research work done in the field of signal design especially in India and also across many countries for both homogenous and mixed traffic conditions. Vehicle emissions are found to cause a lot of health related problems among people due to long time exposure in polluted air at junctions during peak hours of traffic. A detailed account of the studies carried on environmental impact followed by health related problems. .

i) According to California Department of Transportation (Caltrans Varaiya, 2001), if the average speed drops below 35 mph for 15 minutes or more it is defined as congestion whereas in Minnesota, freeway congestion is defined as traffic flowing below 45 km/h for any length of time in any directions (Bertini, 2006). In South Korea, Korea Highway Corporation (KHC) identifies congestion spots where vehicle speeds fall below 30 km/h or traffic congestion continues longer than 2 hours a day that is occurring for 10 days a month. In Japan traffic congestion is defined with respect to free way speed i.e. if freeway travel speed falls below 40 km/h, if there are repeated 'Stop-and-Go' flows for more than 1 km, or if these conditions stay more than 15 minutes. This has been reported in the technical article by Geetam Tiwari [2]

ii) According to Weisbrod and Dewees (1978)., Traffic congestion is a condition of traffic delay because the number of vehicles trying to use the road exceeds the traffic network capacity to handle. A simulation program was used successfully in terms of high accuracy of classifying the road as estimating the external time costs that an additional vehicle using a congested city street imposes on other motorists on that street. This is useful in estimating the burden of congestion on general public and this is reported by Prasanna Kumar[3] .

iii) Roy[4] et. al. (2011) worked on a novel and interesting way to detect the congestion on the urban arterials in India. They suggest using a Wi-Fi signal emitting device and a receiver across the road to identify the congestion. This method was found suitable for congested or free flowing roads. Sun Ye (2012) studied congestion charging practice in Singapore and London and developed a scientific plan for public transportation development. Another research was also conducted for Dhaka city; Bangladesh (2013), estimated congestion cost for a year was USD 3.868 billion that includes the cost of environment damage, vehicle operating cost, social cost, travel time cost etc.

iv) Nithya Swaminathan et.al have attempted to design traffic signal cycle timing using simulation technique, based on vehicle actuation that has resulted in 28% savings in time in the form of standing delay compared to fixed time signals.

v)) Bengaluru Traffic Police are working on VAAS-Vehicle Actuated Adoptive Signals on Outer Ring

Road near K.R. Puram and Om Shakthi Temple junction. The real effectiveness of the modified method of signal design based on vehicle actuation is still under observation for further extending the system to other junction locations. The problem with the vehicle actuated signals is that, if in five minutes there are about 120 vehicles arriving on a particular road, then the mean time of arrival is two and half seconds. Fixing this time interval is always a problem in mixed traffic situations. This information is reported by Traffic police in the Annual Report.

vi) Snigdha. S. S (Dissertation Report, DSCE-Bengaluru-78, 2015) has worked on System Delay that is defined the total loss of time at the junction in the form of standing delay is about 1500 hours per day during signal operating duration of 15 hours in a day. The reason for the delay is attributed to the split green time for major roads that results in queuing on major a road as turning of vehicles not allowed during bi-directional vehicular moment. This makes the signal system less efficient. The saturation flow is also found to vary with respect volume of traffic. But this is assumed to be constant in all signal design methods.

vi) Studies conducted (Project Work, DSCE,2019) at one of the busy signalized intersection on Ring Road near Kamakya Theatre indicates that the green phase of the two opposite minor roads is in excess of 50 % as required for the actual traffic volume and saturation flow conditions. It also indicates, the number of signal cycles can be increased from present 324 to 560, almost 80% more than in a day. This indicates, the signals designed based on IRC recommendations may not be very real indicative of the requirement green time for any road in a day during signal operation time. Also, the green time allocated is more than what is required for main roads provided for simultaneous traffic movement. The total cycle time may be reduced from 150 seconds to 90 seconds at any given point of time.

vii) Snigdha .S.S [9]It is estimated that for a medium flow at the junction carrying 65,000 to 75,000 mixed vehicles per day, there is an estimated 1500 hours of delay per day. On the other hand if dynamic or variable traffic volume and variable saturation flow condition are applied and signal phases are designed then , it is possible to save about 50% of the loss i.e. about 750 hours per day. This also amounts to savings of enormous amount of fuel per day in one junction.

3. Effect of Vehicle Emission on Air Pollution and Impact on Public Health

Extensive studies are already conducted across various places about the ill effects of air pollution on human health as reported in references [10,11 and12]. Bengaluru is the 5th largest metropolitan city of India's and branded as one fastest growing metropolises in the world has a rapidly deteriorating environment due to ill planned and inadequate public transport system and road network. The city Transport Service has only between 6,500-7,000 public buses to carry 45% of the city's traffic. Bengaluru has 80 lakhs as registered vehicles under the non-transport category, of which 55 lakhs are two-wheelers. According to KSPCB data, vehicular emission is the dominant source (42%).Bengaluru in this sense poses more of a risk, as several reports have said that the city traffic is the slowest in the country and commuters in the city on an average spend as much as 7% of their time on the road due to poor road network, bad road condition and high density of traffic. In 2005, traffic moved at the speed of 35km an hour; in 2014, it had slowed down to 9.2km. Today, at peak times, the speed is just 4-5km on the city's key Outer Ring Road. At traffic junctions, the wait time is more than five minutes when it should ideally be not more than two-three minutes.

i) According to KSPCB data, $PM_{2.5}$ and PM_{10} particulate matter values have exceeded the National Ambient Air Quality Standards (40 μg/m3) by 3% to 45%, at junctions due to vehicular traffic increase in vehicular delays. The PM_{10} values have also exceeded the National Ambient Air Quality Standards (60μg/m3) by 30% to 120% at junctions. Medical expert opine that particulate pollution gets

absorbed into the bloodstream within a few minutes and is responsible for blocking the arteries leading to heart attacks.

ii) The city has witnessed a phenomenal growth in vehicle population without commensurate increase in either the road space. The WHO ranks air pollution as the 13th leading cause of world-wide mortality, with 527,000 people annually dying prematurely in India due to air pollution. Bangalore is experiencing varying levels of pollution with certain areas having either high or critical levels of the pollutants analysed by Karnataka State Pollution Control Board study. The critical levels of Particulate Matter are likely to have a damaging effect on the health of the citizens in Bangalore that may result in a tremendous burden on the public health system. Also this is affecting the skilled young human resource. This issue of health impact due to air pollution should be addressed by effective and practical measures. The major pollutants constituent is $PM_{2.5}$ and PM_{10} that indicates the mean diameter of particles present in the air that enters through the repository track and gets deposited along wind pipe (Alveolar Region) of the lung. Keeping all the above pints in view, it is absolutely necessary and essential to carry research for immunizing vehicular emissions at junctions by adopting an innovative and advanced method of signal design that can cater to the signal cycle to satisfy variable mixed traffic volume followed variable.

4. Comparison of Existing Method and Proposed Method of signal Design

In the proposed method of signal design the traffic volume and saturation flow data is stored in the Excel sheet format with respect to time of the day in a block period of five minutes and the program draws these values and uses in the equation for calculating optimum cycle length for the junction and apportioned in the proportion of the respective traffic volume on respective roads, including time for pedestrians and Amber time. The complete signal design process is depicted in the following figures.

Fig 1 Plot of Traffic volume Vs Hour of the day indicating variation with respect to time of the day, calculation of signal cycle time for peak hour of the day and calculation of peak hour traffic volume by four fifteen counts and averaged for one hour is also shown to calculate the peak hour design traffic volume. For a given junction it may be either morning or afternoon peak as the case may be. In the present method the design volume is taken every block period of five minutes for the design of signal cycle time to be more on realistic side.

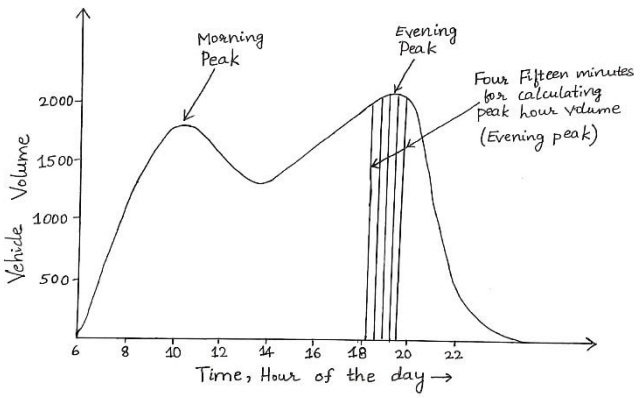


Figure 1: Variation of traffic volume at junctions in a day and peak hour volume calculation.

Fig 2 provided below shows the IRC method of calculating the saturation flow and for a given road width this value is assumed as a constant. The initial lag time during starting delay is normally 2 to 3 seconds is indicated as 'x'. In the tail end of the curve 'y'. Here 'y' indicates saturation head way and at the end of this the vehicles flow freely till the end of green time. In the present modified method, the saturation flow is considered as a variable for calculating value green time in a block period of five minutes.

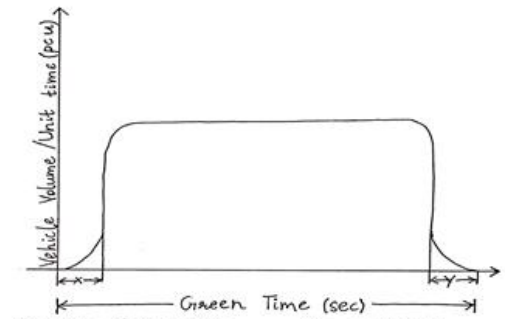


Figure 2 : Saturation flow – Homogeneous traffic

x : Initial lag during starting and accelaration, sec

Y: End of saturation flow and saturation end headway, sec

Fig 3 provided below shows the variation of saturation flow in mixed traffic flow situation. This shape of the curve is as observed in the field during data collection. The curve is obtained in a different fashion, as the field data indicates the domination of two wheelers in the accumulated during red phase of the signal in the front and during the green phase the vehicles accumulated would clear fast and hence the observed volume of vehicles the beginning of the green phase and slowly reduces to a minimum. At the end of the green period the vehicles are under free flow condition. That is one vehicle following the other and this condition is called as saturation headway. In traffic system the free flow of vehicles should never be allowed as it may result in rear end accidents due to sudden change to red phase. In the present method this question does not arise as both the volume and corresponding saturation flow are taken as a mean of three values and signal time is calculated as just what is needed for the vehicle volume and corresponding saturation flow value. This would not result in excess green time that may result in free flow like condition.

Stepped value of volume in a block period of five Minutes for signal cycle time calculation and apportioning it to all the roads in proportion to the volume of vehicles waiting for clearance would result in lowest value of green time for each road and the excess of green time would be minimum for each block period of five minutes. This is also indicated in the Fig (1) which shows the variation of traffic volume in a bloc period of five minutes. This method would totally eliminate the excess of green time due to fixed traffic volume and saturation.

5. Traffic Data Collection and Analysis

This includes study of signal phases from morning to evening for probable change in cycle time during peak hours, study of traffic volume and saturation flow for three cycles in a block period of 15 minutes. Unused green time based on saturation headway as indicated in the figure. Saturation headway is the time headway or inter-arrival time between successive vehicles arrival after platoon movement ends and the vehicles move one behind the other which is termed as lean flow during the end of saturation flow. This value varies from time to time depending on the total number of vehicles that have accumulated during red time and the traffic volume of the road under consideration.

6. Signal Phase Design Based on Webster Method

Based on values of normal flow, the ratio, $y = \frac{q}{s}$ are determined on the approach roads. In case of mixed traffic, the different classes of vehicle volume may have to be converted by multiplying by appropriate PCU values to get volume in PCU. The optimum signal cycle is given as, $C_0 = \frac{1.5L+5}{1-Y}$

Here, L =2n+R and 'R' is phases the total lost time per cycle in second, 'n' is the number is of phases for the junction and for square junction (usually this value 4 for a typical junction that is considered for study), R is the all red time or red-amber time. The green time for a phase is given as $G = \frac{y}{Y}(C_0 - L)$, here Y=sum of 'y' values for all approach roads under consideration. This method uses fixed peak hour traffic volume and saturation flow values.

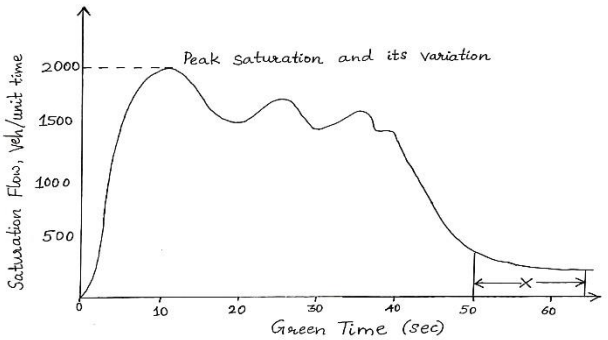
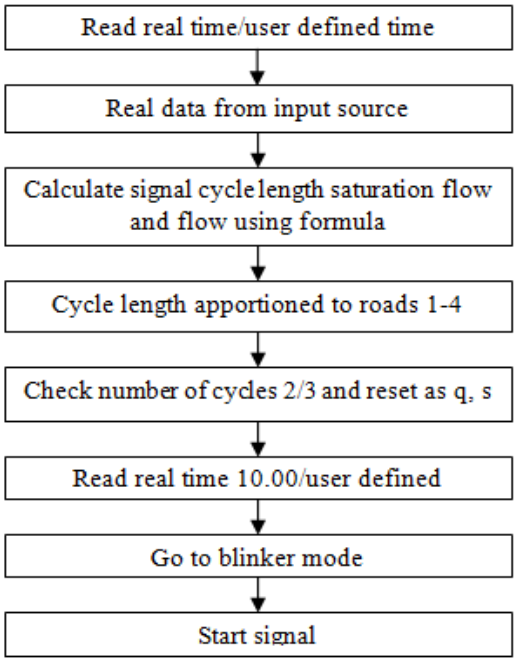


Figure 3 : Saturation flow in mixed traffic condition
x → unused green time / Saturation headway

7. Application of Embedded System in traffic signal cycle design for junctions

An embedded system is the system which has computer hardware with software embedded in it. It is a device which has a programmable computer but not general purpose computer. An Embedded System is controlled by an internal microprocessor or microcontroller instead of an external control unit. Arduino, PIC Microcontroller, 8051 Microcontroller. Atmel Microcontroller are usually used to design embedded systems. In the signal time design for junction, the data may be provided in the format shown in the end and the instructions for the calculation of green time and red time for a bloc period of five minutes is also included and execution of the design of signal phases for all roads may be provided in the table. The data may be provided in the Excel format as shown. Typical sheet containing vehicle flow per unit time, corresponding saturation flow, formulae to be used for the calculation of signal cycle length and computing the green time and red time as required depending on the width of the road and normal walking speed of 1.2 m/sec. The various constants as applicable in the Program may predefined and used accordingly. The controller controls the data flow from source and also time at which a different data set have to be taken for next calculation. The sequence of signal time setting may also be defined in the program. The new set of field data may also be entered in place old data if field situation demands. The table is provided as a typical example wherein, in reality the data format should be designed as required for the junction depending on the of traffic volume and corresponding saturation flow values. This means the signal time is to be designed based on requirement at the junction. Some junction carrying high traffic volume may have to start at 7.00 AM and may go up to 11.00 PM and the data format should incorporate all such details. The data is provided based on field observations on a normal traffic day as the traffic volume is influenced by week of the day like Monday the day after a holiday, Wednesday is a normal day and Saturday is influenced by the next day holiday. Hence, if the data is able to provide all such needed information, then this would be more successful.



Typical Flow Chart for Traffic Data Flow

Table No.1 Format for Input Data for the design of signal phases in a block period of Five minutes

INPUT DATA FORMAT			
Time of the day	Flow value	Saturation flow	Condition equation
7:00	q_1	s_1	$y1 = {}^{q}/_{s}$
7:05	q_2	s_2	
7:10	q_3	s_3	$Co = \frac{1.5L + 5}{1 - y}$
⋮	⋮	⋮	
22:00	q_n	s_n	$Y = \sum y$
			$G = \frac{y}{Y}(Co - L)$

8. Advantages of the proposed method

i) Real time data is used for calculation of cycle time based on actual value as obtained from the field and in no place any assumption is made about the traffic data that makes the green and red time calculation a more realistic one.
ii) No excess of green time is provided for any phase as the calculation is based on actual data at that time.
iii) If the effect of weekday is going to matter, then the table may be further extended to incorporate this.
iv) Overall minimum waiting for vehicles due to less delay and less pollution.

9. Discussions and Conclusions

There is tremendous scope for reducing the vehicle delay at junctions by using variable value of volume and saturation flow in adopting the dynamic values of both volume and saturation flow values in arriving at optimal signal time. For more accurate assessment value of the delay, a block period of five minutes may be assumed. If more accuracy is desired then program real time data may be provided directly to the system from video camera connected to the program.

10. Scope for Further Study

i) Real time, time headway may be captured for all roads at a junction using high resolution video cameras, followed by real time flow and saturation flow values are worked out and substituted in the relevant equations for calculating actual green time for the for each road separately and assigned to that signal phase for the road.
ii) This concept may be extended for all roads at a junction for each cycle for optimal performance to minimize the delay.
iii) The recommended method of data collection, data storing and using it for real time computation of signal cycle time for all roads at the junction would result in minimizing delay and also reduced vehicular emission and hence less air pollution.
iv) This logic of signal design may be extended to all junctions using cloud data storage method and computing green time, amber time and total cycle time on real time basis.
v) Calculation of system delay before and after the proposed method may be worked out to calculate the overall savings in productive time, fuel and reduction in pollution due to reduced vehicular emissions.
vi) The study may be extended to the entire city and the loss of fuel has to **assessed** for preventive measures for reduction in time loss and fuel loss for further optimizing each signal location and signal phase. From this nearly half the fuel wasted at signalized may be eliminated.

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