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Improvement of Signalized Urban Intersection Through Optimization of Signal Timing

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Abstract

Intersections are one of the most critical elements that affect the performance of urban road network. For safe and efficient movement of large volumes of traffic on city road network. Saturation flows, lost times and Passenger Car Units (PCU) are the significant parameters in the planning, design and control of signalized intersection. The accurate estimation of saturation flow values is prime importance when determining the capacity of signalized intersection. KKV intersection is one of major intersection of Rajkot city. Considering the saturation flow at KKV intersection, optimization of signal timing was done. In present scenario, cycle length of KKV intersection is 250seconds, so that signal delay at all approaches is more than 170seconds. These problems can be overcome with signal optimization. It is done with three phases and four phases and found that cycle length is decrease as 157 sec as well as delay is also decreasing at all approaches.
Keyword- Heterogeneous traffic, Optimizing signal time, Saturation flow rate

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I. INTRODUCTION

Traffic signals are perhaps the most important traffic control devices for at intersection in the urban traffic system. Proper installation of traffic signals can reduce the number of accidents and minimize delays to vehicles at intersections. Road traffic conditions in India get worse day by day. Spending hours in traffic jam have become part and parcel of the metropolitan lifestyle, leading to health and environmental hazards.

In order to solve this problem, there could be two approaches: The first approaches are to come up with infrastructure involving wider roads, flyovers, bypasses and expressways. But this approaches solutions area very serious concern about space and money for developing countries like India. The second approach is to manage existing traffic with the same infrastructure, with the use of technology and by involving commuters in the process. Concentrating on the second approach that is an Intelligent Transportation System (ITS) which makes use of communication technology to alleviate road traffic problems. Different ITS techniques aim to provide information like current road congestion level, predicting travel time, predicting traffic congestion. Commuters can make use of this information to plan their travel better- by choosing a less congested road if there is a choice, by adjusting traveling time to avoid peak-traffic hours. It will be necessary to review the traffic signal timing. For a particular intersection, cycle time is an important parameter to minimize delays that ultimately cause formation of long queues and accidents. An important component required for the optimum cycle time is saturation flow.

A. *Objectives of Study*

- To collect traffic data and estimate the saturation flow rate at KKV intersection of Rajkot city.
- To optimize intersection signal timing with consider prevailing saturation flow of KKV intersection for vehicles.

II. BASIC CONCEPT OF SIGNAL DESIGN

A. *Overview*

Traffic signals are one of the most effective and flexible active control of traffic and is widely used in several cities world-wide. The advantageous of traffic signal includes an orderly movement of traffic, an increased capacity of the intersection and requires only simple geometric design. However, the disadvantageous of the signalized intersection are large stopped delays, and complexity in the design and implementation.

B. *Terminology and Key Definitions*

1) Cycle: One complete sequence of signal indications, start green time on one phase to start of green again on the same phase is called a cycle.
2) Cycle Length (C): Total length of time for the signal to complete one cycle. Phase: The sequence of conditions applied to one or more streams of traffic during which the cycle receive identical signal light conditions.

3) Change Interval (Y): The "yellow" and /or "all-red" intervals, which occur at the end of a phase to provide for clearance of the intersection before conflicting movement are released.
4) Green Time (G): Time within a given phase during which the "green" indication is shown.
5) Lost Time: Time during which the intersection is not effectively used by any movement or the amount of a time in a cycle, which is effectively lost to the traffic movement in the phase because of starting delay, and at the end of green phase with start of amber period. Pedestrian movement at start of phase and the falling of the discharging rate, which occurs during the amber period.
6) Effective Green Time: Time during which a given phase is effectively available for stable moving platoons of vehicles in the permitted movements.
7) Green Ratio: Ratio of effective green time to the cycle length.
8) Effective Red: Time during which a given movement or set of movements is effectively not permitted.
9) Saturation Flow Rate: Saturation flow is the maximum volume stated in passenger car unit / hour (PCUs/h), which can pass the stop line of approach lane at a green light.
10) Optimum Cycle Time: The cycle time, which gives the least average delay to all vehicles using the intersection.
11) Phase: A phase is the green interval plus the change and clearance intervals that follow it. Thus, during green interval, non conflicting movements are assigned into each phase. It allows a set of movements to flow and safely halt the flow before the phase of another set of movements start.

C. Major Steps for Signal Design

1) Phase Design

The objective of phase design is to separate the conflicting movements in an intersection into various phases, so that movements in a phase should have no conflicts. If all the movements are to be separated with no conflicts, then a large number of phases are required. In such a situation, the objective is to design phases with minimum conflicts or with less severe conflicts. There is no precise methodology for the design of phases. This is often guided by the geometry of the intersection, flow pattern especially the turning movements, the relative magnitudes of flow. Therefore, a trial and error procedure is often adopted.

a) Two phase signals:

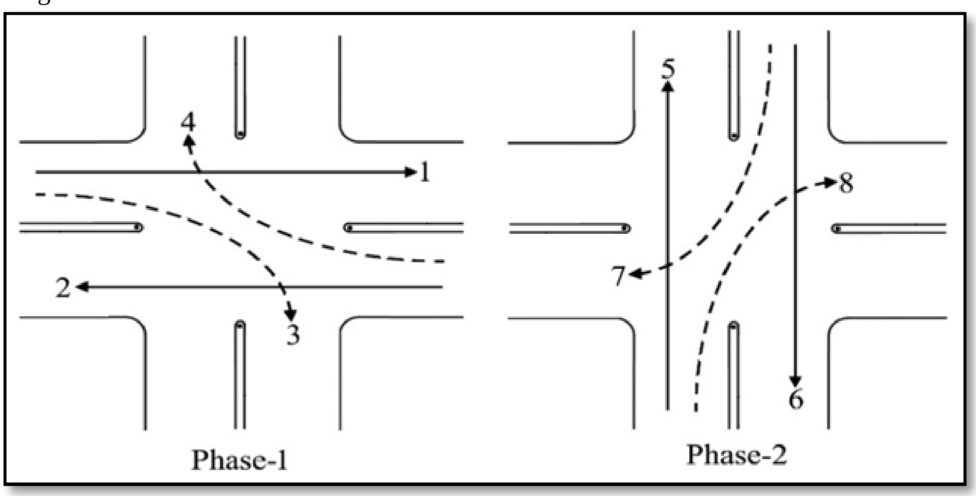


Fig. 2.1: Two Phase Signal

Two phase system is usually adopted if through traffic is significant compared to the turning movements. For example in figure 2.1, non-conflicting through traffic 1 and 2 are grouped in a single phase and non-conflicting through traffic 5 and 6 are grouped in the second phase. However, in the first and second phase flow 3, 4 and 7, 8 offer some conflicts and are called permitted right turns. Needless to say that such phasing is possible only if the turning movements are relatively low.

b) Four Phase Signals:

There are at least three possible phasing options. For example, figure 2.2 shows the most simple and trivial phase plan. Where, flow from each approach is put into a single phase avoiding all conflicts. This type of phase plan is ideally suited in urban areas where the turning movements are comparable with through movements and when through traffic and turning traffic need to share same lane. This phase plan could be very inefficient when turning movements are relatively low.

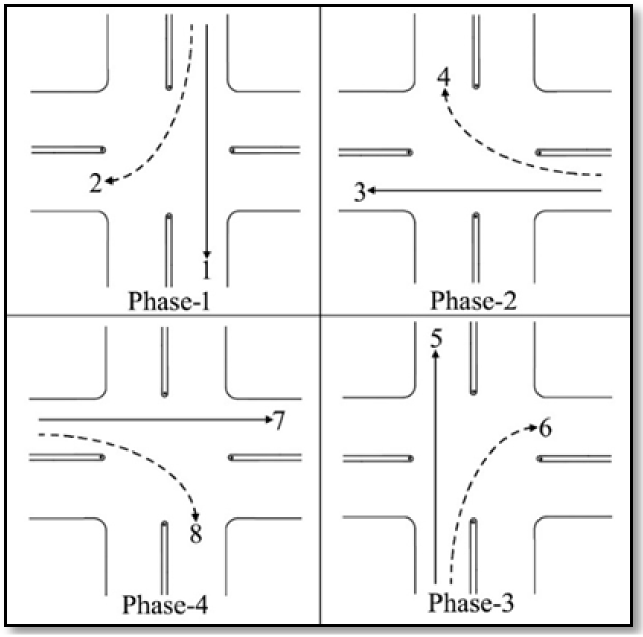


Fig. 2.2: One way of providing four phase signals

Figure 2.3 shows a second possible phase plan option where opposing through traffic are put into same phase. The non-conflicting right turn flows 5, 6 and 7, 8 are grouped into a third and fourth phase respectively. This type of phasing is very efficient when the intersection geometry permits to have at least one lane for each movement, and the through traffic volume is significantly high. Figure 41:5 shows yet another phase plan. However, this is rarely used in practice.

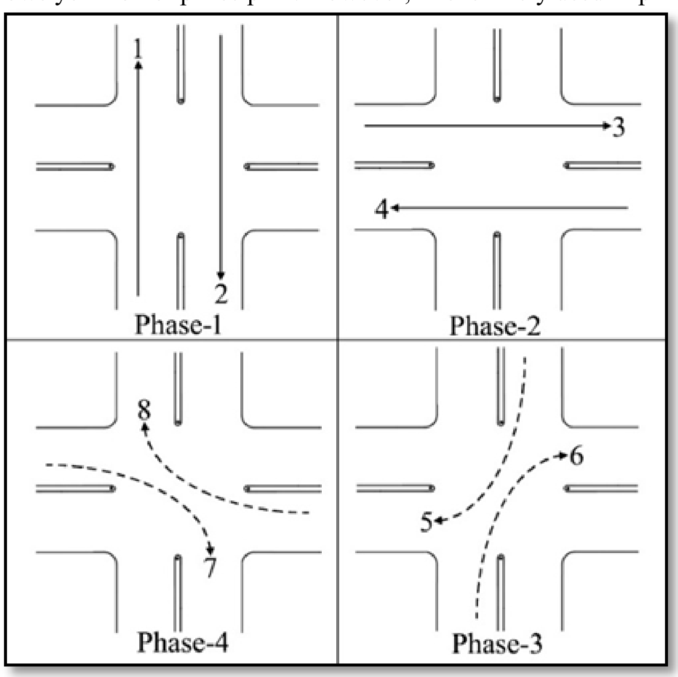


Fig. 2.3: 2nd possible way of providing a four phase signal

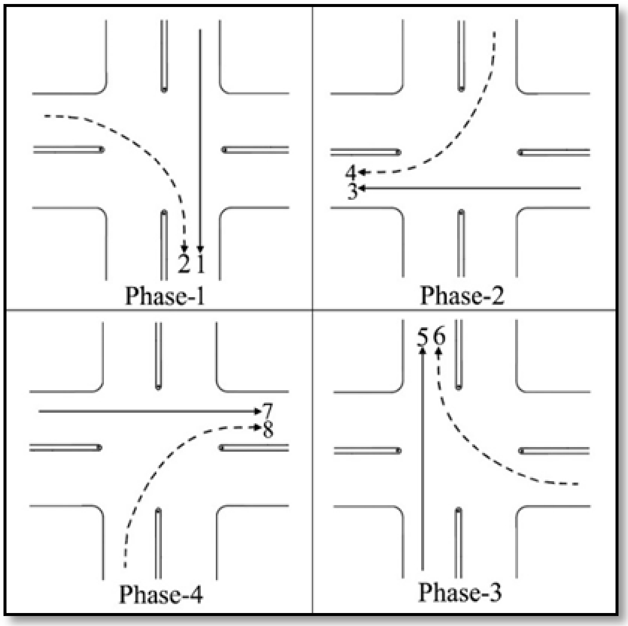


Fig. 2.4: 3rd possible way of providing a four phase signal

D. Interval Design

There are two intervals, namely the change interval and clearance interval, normally provided in a traffic signal. The change interval or yellow time is provided after green time for movement. The purpose is to warn a driver approaching the intersection during the end of a green time about the coming of a red signal. They normally have a value of 3 to 6 seconds.

E. Optimum Cycle Time

One of the important steps in designing a fixed time signal system is to determine the cycle time. Main consideration in selecting the cycle time should be that the least delay is caused to the traffic passing through the intersection. For each traffic flow volume there is an optimum cycle time which results in the minimum delay to the vehicles.
By differentiating the equation for the total delay for the intersection with respect to cycle time, the following equation for the optimum cycle time has been obtained:

$$\mathrm{Co} = \frac{1.5\ \mathrm{L} + 5}{1 - \mathrm{Y}}\ \text{seconds}$$

Where Co = optimum cycle time (in seconds)
L= Total lost time per cycle (in seconds)

$$Y = y_1 + y_2 + y_3 + \ldots\ldots + y_n$$

And y_1, y_2, y_3 …y_n are the maximum ratios of flow to saturation flow for phases 1, 2…n. (i.e. *q* / *s* where *q* is the flow and *s* is the saturation flow).
The lost tike *L* in the above formula can be understood with reference to figure 2.5, indicating the rate of flow against time.

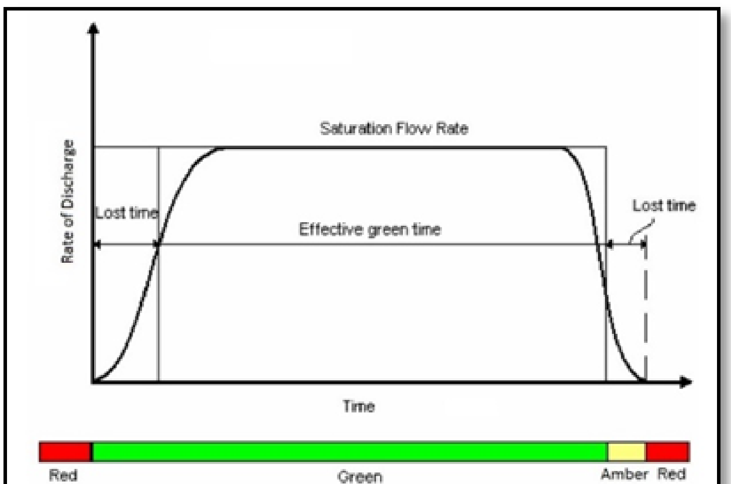


Fig. 2.5: The flow of traffic during the green period from a saturated approach

The figure 2.5, shows that as soon as the green signal is given, the rate of discharge begins to pick up and some time is lost before the flow reaches the maximum value (saturation flow). Similarly at the termination of the green of phase, the flow tends to taper off, involving a further lost time. The lost time for the phase would then be:

$$l = k + a - g$$

Where l = lost time for the phase;
k = green time for the phase;
a = amber time for the phase;
g = effective green time = b/s;
b = number of vehicles discharged on the average during saturation flow.;
s = saturation flow.

The total lost time due to starting delays per cycle will be nl if there are n phases in the cycle. In addition to this lost time, the time R during each cycle when all signals display red (including red/amber) simultaneously is also lost to the traffic. Thus the total lost time L can be expressed as:

$$L = nl + R$$

In determining the *y* value, the saturation flow should be measured rather than estimated value. The method of measuring the saturation flow is described in a Road Research Laboratory publication. For designing new signal installations, the following simple formula devised by the Road Research Laboratory, U.K. can be used:

$$s=525\ w\ \text{PCU/hour*}$$

Where s = Saturation flow;
w = width of approach road in meter.
*Note: This formula is valid for width of from 5.5 to 18 m.

2) Effective Green Time (g_i):

Effective green time is the actual time available for the vehicles to cross the intersection. It is the sum of actual green time (G_i) plus the yellow (a) minus the applicable lost times. This lost time is the sum of start-up lost time (l_1) and clearance lost time (l_2) denoted as L. Thus effective green time can be written as,

$$g_i = G_i + a - L$$

Where g_i = Effective green time in seconds;
G_i = Actual green time in seconds;
a = Amber time in seconds;
L = Total lost time in seconds.

III. LITERATURE REVIEW

Chang-qiao Shao, Xiao-ming Liu (2012), "Estimation of Saturation Flow Rates at Signalized Intersections" The goal of this paper is to study the nature of queue discharge headways and to develop a more accurate estimate method for saturation headway and saturation flow rate. Based on the surveyed data, the characteristics of queue discharge headways and the estimation method of saturated flow rate are studied. It is found that the average value of queue discharge headways is greater than the median value and that the skewness of the headways is positive. According to the queue discharge headway characteristics, the median value of queue discharge headways is suggested to estimate the saturation headway and a new method of estimation saturation flow rates is developed.

The average value of queue discharge headways is greater than the median value, and the skew of headways is positive. The traditional estimation of saturation headway does not accurately reflect the true value of headway. The new estimations of saturation flow rate developed in this study are more reasonable and they are suggested to be used in traffic control and measurement of intersection capacity.

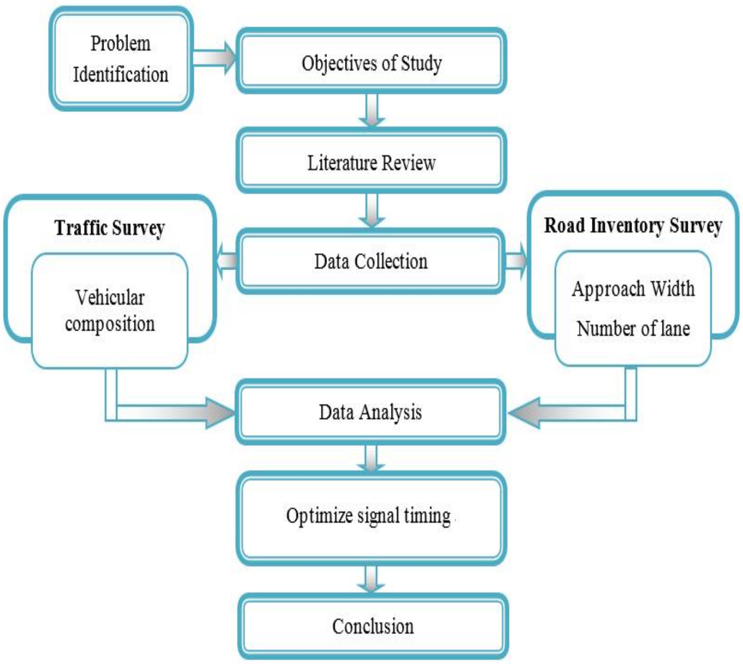
M. R. Chaudhary et al. (2014), "Traffic Signal Design and Co-Ordination between Two Intersections of Dhansura-Shamlaji Road- A Case Study of Modasa City" There are two objectives for this research. One is to develop an effective procedure to optimize intersection signal timing by minimizing total delay for both vehicles and pedestrians. The second objective is to establish guidance for pedestrian crossing phase selection and the length of WALK phase when scramble crossing is used. An optimization procedure for signal plans on intersections is developed. The object of this report is to give traffic engineers or technicians in the cities of the emerging world a brief introduction to traffic signals, together with some practical guidelines on how to use them to obtain good and safe results. The lack of traffic signal conspicuity is often cited as a contributing factor by drivers who are involved in accidents at intersections. As such, increasing the conspicuity of traffic signals should lead to improved safety performance. This paper describes a project to determine the road safety effectiveness associated with improved signal design and better co-ordination between two intersections.

IV. METHODOLOGY AND DATA COLLECTION

A. Methodology

For the data collection to measure saturation flow there are different methods, ranging from manual to complex automatic techniques. All these methods have some merits and demerits. Any method, which should be selected for any study depends on many factors like the type of study, availability of manpower, ease of analysis, cost and should provide a permanent record of data for further analysis at any time.

Since it will need two or more observers to collect the necessary data manually, it was decided to use a Video Recording technique for data collection.



B. Data Collection

KKV intersection is four-legged intersection. During peak hours (Morning peak and Evening peak), the intersection gets over saturated. Traffic flow at intersection, approaching from Kalawad, Madhapar chowk, Kotecha circle and Gondal chowk. The geometrical features at this intersection as shown in figure 4.1. Traffic consists of two wheelers, Car, Auto, LCV, HCV, Bus, and Bicycle.

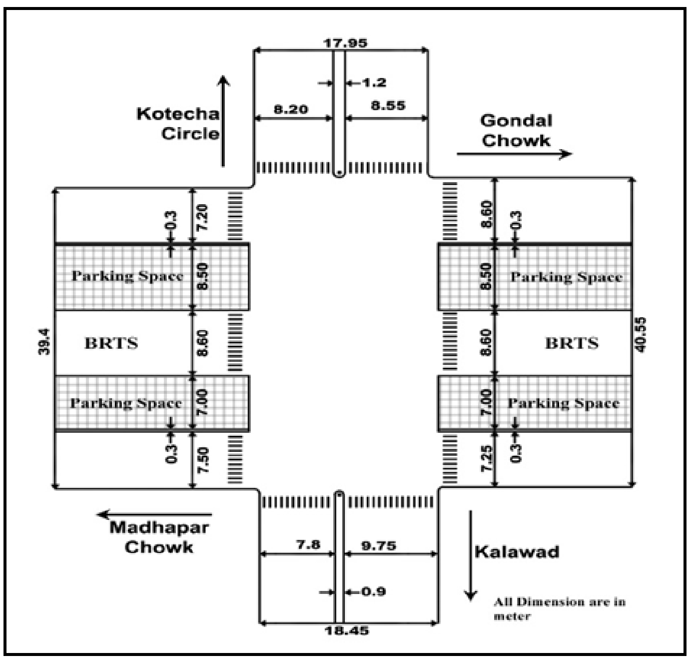


Fig. 4.1: Road features of KKV circle

C. Traffic Composition at Intersection Approaches

Following vehicles composition is observed during morning and evening peak period for the KKV intersection.

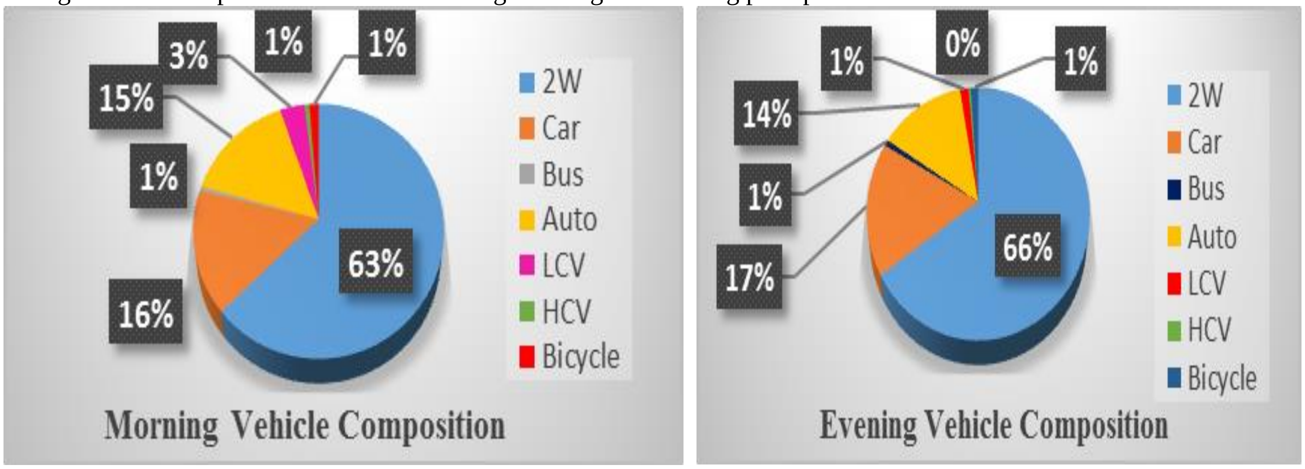


Fig. 4.2: Average traffic composition at KKV intersection in Morning and Evening peak

Here, Table 4.1. Shows classified volume data with three directions Left (L), Straight (S), Right (R). Data collected for both morning peak hours and evening peak hours.

Time	*Approach*	*2-Wheel*			*Car*			*Bus*			*Auto*			*LCV*			*HCV*			*Bicycle*		
		L	*S*	*R*	*L*	*S*	*R*	*L*	*S*	*R*	*L*	*S*	*R*	*L*	*S*	*R*	*L*	*S*	*R*	*L*	*S*	*R*
10:30AM To 12:45PM	*Kotecha*	*0*	*3516*	*817*	*0*	*692*	*157*	*0*	*36*	*0*	*0*	*745*	*137*	*0*	*111*	*30*	*0*	*0*	*0*	*0*	*66*	*38*
	Gondal	*357*	*582*	*742*	*130*	*154*	*204*	*4*	*3*	*3*	*64*	*262*	*122*	*47*	*24*	*26*	*39*	*0*	*1*	*8*	*15*	*11*
	Kalawad	*261*	*2677*	*804*	*66*	*617*	*260*	*0*	*38*	*10*	*78*	*709*	*127*	*31*	*137*	*56*	*19*	*2*	*24*	*6*	*42*	*7*
	Madhapar	*374*	*593*	*283*	*134*	*213*	*115*	*0*	*5*	*1*	*142*	*157*	*123*	*7*	*103*	*35*	*1*	*2*	*33*	*15*	*18*	*4*
6:15PM To 8:15PM	*Kotecha*	*0*	*3279*	*728*	*0*	*728*	*188*	*0*	*32*	*1*	*0*	*546*	*116*	*0*	*26*	*33*	*0*	*0*	*0*	*0*	*0*	*8*
	Gondal	*307*	*579*	*613*	*108*	*142*	*160*	*5*	*7*	*4*	*45*	*240*	*59*	*4*	*12*	*4*	*22*	*0*	*0*	*8*	*42*	*6*
	Kalawad	*192*	*2052*	*643*	*46*	*480*	*244*	*5*	*30*	*21*	*67*	*461*	*83*	*9*	*68*	*15*	*5*	*0*	*5*	*17*	*33*	*11*
	Madhapar	*256*	*557*	*272*	*65*	*221*	*91*	*0*	*4*	*3*	*67*	*197*	*63*	*2*	*16*	*8*	*0*	*0*	*16*	*21*	*22*	*6*

Table 4.1: Classified Volume data at KKV Intersection

V. DATA ANALYSIS

For optimized signal timing table 4.1 data required and that data are analyzed as below. For signal design maximum saturation flow from morning and evening data of individual approach.

From	*Kotecha*			*Kalawad*			*Gondal*			*Madhapar*		
To	*L*	*S*	*R*	*L*	*S*	*R*	*L*	*S*	*R*	*L*	*S*	*R*
V (PCU/hr)	*0*	*1464*	*348*	*147*	*1085*	*365*	*228*	*273*	*271*	*325*	*308*	*215*
S (PCU/hr)	*7586*			*6763*			*6585*			*6445*		
q	*1811*			*1598*			*773*			*849*		
y_i	*0.24*			*0.24*			*0.12*			*0.13*		
	Y_1			Y_2			Y_3			Y_4		

Table 4.2: Data analyzed for signal design.

Here, signal is design adopting four phase signal.

Total Lost time (L) = n ($l + l_1$) + R = 4*(3+3) +2=26 second

Where, n=Number of phase, l=Amber time in sec., l_1=Starting lost time in sec. R=Red time (when all approach signal is red) in sec.

$Y = Y_1 + Y_2 + Y_3 + Y_4 = 0.24 + 0.24 + 0.12 + 0.13 = 0.72 < 1$

Optimum cycle time $Co = \frac{1.5\,L+5}{1-Y}$ $seconds,$ $= \frac{1.5*(26)+5}{1-0.72} = 157$ sec.

Effective Green time $= Co - L = 157 - 26 = 131$ sec.

Green time for Kotecha & Kalawad Approach (g1) $= \frac{Y1}{Y}(Co = \frac{0.24}{0.72}(131) = 43$

Green time for Kalawad Approach (g2) $= \frac{Y2}{Y}(Co = \frac{0.24}{0.72}(131) = 43$ sec.

Green time for Gondal Approach (g3) $= \frac{Y3}{Y}(Co = \frac{0.12}{0.72}(131) = 21$sec.

Green time for Madhapar Approach (g4) $= \frac{Y4}{Y}(Co = \frac{0.13}{0.72}(131) = 24$sec.

Total Cycle Time = 41+47+24+22+32 = 157 sec.

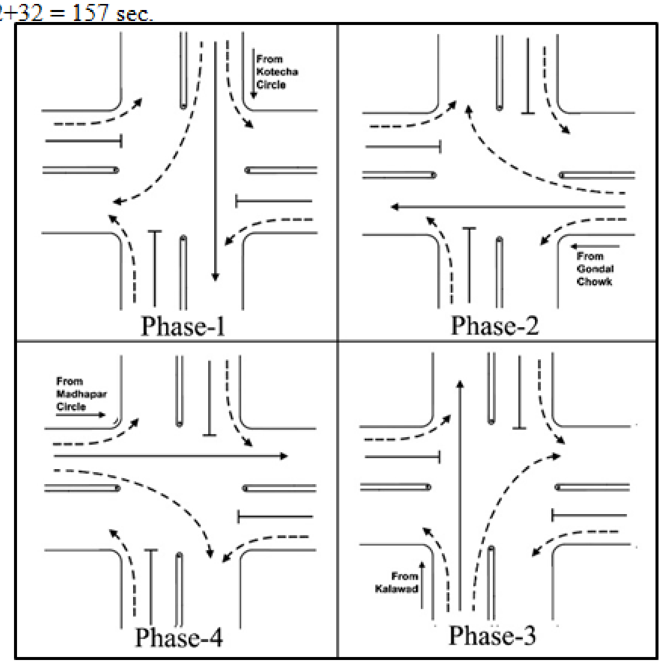


Fig. 5.1: Four Phase Diagram for KKV Intersection

VI. Conclusion

- This paper analyzes the saturation flow rate using field data from KKV intersections of Rajkot city.
- As per the vehicle composition, a four phase system is adopted for signal optimization.
- It has been found that the present cycle time of KKV intersection is 250sec. and delay at all approaches can be optimized with 157 Sec. effective green time is 131 sec, amber time is 3sec. and starting lost time is 3sec.

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