Proceedings of the 8th International
IEEE Conference on Intelligent Transportation Systems
Vienna, Austria, September 13-16, 2005

Analyses of Vehicular Delays and Queues at Intersections With Adaptive and Fixed Timing Control Strategies

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Abstract—**In this paper, we develop a queuing model for a traffic-adaptive strategy to control a 2-phase intersection. The strategy is an approximation of the RHODES strategy [1], which essentially "switches to next phase when the served queue clears." In fact, Newell was the first to compare such a strategy with rolling horizon using a continuous-time formulation [2]. This model can be used to analyze vehicular delays and queue distributions at an intersection with a two-phase signal, where the vehicle arrival process is Poisson, for both fixed timing signal control and traffic-adaptive signal control. Numerical results for the two control strategies are provided and compared.**

I. INTRODUCTION

There are lots of studies focusing on modeling traffic flow at signalized intersection. Stephanopoulos and Michalopoulos presented a method to model and analyze traffic queue dynamics at signalized intersections based on the linear flow-density model [3]. Newell made a comparison between the rolling horizon strategy of traffic signal control and the strategy of switching the signal when a queue vanishes [2]. In these papers the traffic volumes are assumed to be uniformly distributed. Olszewski developed a stochastic model of signalized intersection, using this model we can analyze the delay and queue distribution of an intersection with stochastic arrival [4]. Simulation is another popular approach. Zhang, et al, described the process by which control delay could be determined in the CORSIM module of TSIS 5.0 [5]. Tian, et al, have compared the results of various traffic simulation models to the Highway Capacity Manual (HCM) (2000) [6]. These studies usually focus on comparing the results produced by different models and make recommendations on which simulation model better replicates the results of either the HCM or field data. In this paper, we propose a method to analyze the signalized intersection with Poisson arrivals theoretically.

Base on the known distribution of busy period of *M/G/***1** system, we analyze the distribution of busy period of the intersection with multiple vehicles waiting at the beginning of a green phase. Then we consider two types of traffic signals, adaptive signal and fixed timing signal. With Poisson arrival, the adaptive traffic signal serves one direction till its queue is cleared, and then it switches to serve the other one. The fixed timing signal is set based on the degree of saturation of two directions. In the first case there is no residual queue at the end of green phase, while the green phases are random variables. With fixed timing signal, a residual queue may exist. By calculating the probabilities of all scenarios of the system in each half cycle, we can get the distribution of the system variables, including total delay, average delay, expected green phase length for

adaptive case and optimal signal setting for fixed timing case. The start point of the adaptive case is set as the steady state of the same intersection (same arrival rates and service rates on corresponding directions) with uniform vehicle arrivals, because it is stable and close to the steady state of the stochastic system. For the fixed timing case, assume there is no residual queue at the beginning. We keep using the numerical method till it reaches steady state. The results of two systems are compared, some conclusions are made, and the future works are pointed out.

II. BUSY PERIOD ANALYSIS

In a general queuing system, a busy period begins when a customer arrives to find the server free to deal with him at once (i.e., there is a zero queue). A busy period ends when the server completes the service of a customer and finds there are no customers presently demanding service (i.e., there is a zero queue again). The interval between the end of a busy period and the beginning of the next constitutes a free period. For an *M/G/***1** system, the free period has a negative exponential distribution. The distribution of the busy period of *M/G/***1** system is analyzed in many queuing theory textbooks. Here we consider a different situation, in which multiple vehicles form a queue at the beginning of a green phase, what's the expectation of the time needed to clear the queue?

Vehicle arrival follows Poisson distribution with parameter λ, the service rate (saturation flow rate) of the intersection is μ. If there is only one vehicle waiting at the beginning of the green phase, and q represents the expectation of busy period. The expectation of q is

$$E(q) = \frac{1/\mu}{1-\lambda/\mu} \quad (1)$$

Manuscript received March 1, 2005.

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By using s-transform we prove the expectation of busy period caused by k vehicles is k times of the expectation of busy period caused by one vehicle.

$$E(q)=\frac{k/\mu}{1-\lambda/\mu} \quad (2)$$

III. ADAPTIVE SIGNAL CONTROL

In this paper we consider an isolated two direction intersection without turning movement. The arrival rate and service rate of W-E direction are λ_1 and μ_1, those of N-S direction are λ_2 and μ_2. The stability condition of the intersection is satisfied, that is, the summation of degrees of saturation $\rho_1+\rho_2$ ($\rho_i=\lambda_i/\mu_i$) is less than 1. The time axis is divided into half cycles for the convenience of analysis. Each half cycle, c_i, is composed of a constant time lost L plus a green phase. The odd subscript of c means it serves W-E direction, even subscript means it serves N-S direction.

If vehicle arrival is uniformly distributed, optimal signal settings are deterministic. The length of c_2 (serves N-S direction) is equal to L plus the time needed to serve the vehicles arrived in N-S direction during the whole cycle. The W-E direction is similar. The optimal half cycle lengths of two directions are [2]

$$c_1=\frac{1+\rho_1-\rho_2}{1-\rho_1-\rho_2}L \quad (3a)$$

$$c_2=\frac{1-\rho_1+\rho_2}{1-\rho_1-\rho_2}L \quad (3b)$$

Set c_1 and c_2 by (3), and vehicle arrivals of two directions are uniformly distributed during c_1. At the beginning of c_2 (c_3), vehicle arrivals of W-E (N-S) direction change into Poisson process. The arrival rates don't change.

The adaptive signal serves one direction till the queue is cleared, and then it switches to the other direction, so on and so forth. Here c_1 and c_2 are deterministic, c_3, $c_4 \ldots c_n$ are random variables, their distributions depend on time needed to serve the queue. We propose a method to calculate the distribution of these random variables. Based on the distribution of the half cycles, one can calculate the distribution of delay and queue length.

Define X_{2i} (X_{2i+1}) as the number of vehicles arrived in W-E (N-S) direction in ($c_{2i}+L$) (($c_{2i+1}+L$)). The pmf (probability mass function) of X_2 is

$$P_{k_2}=P(X_2=k_2)=\frac{[\lambda_1*(c_2+L)]^{k_2}}{k_2!}e^{-\lambda_1*(c_2+L)} \quad (4)$$

The expected green phase length (c_3-L) is

$$c_3-L=k_2*\frac{1/\mu_1}{1-\rho_1} \quad (5)$$

The traffic signal switches as the queue vanishes, which means vehicles depart at saturation flow rate during the whole green phase. Thus the total number of vehicles served in (c_3-L) is

$$S_3=(c_3-L)*\mu_1=k_2*\frac{1/\mu_1}{1-\rho_1}*\mu_1=\frac{k_2}{1-\rho_1} \quad (6)$$

To calculate the total delay of W-E direction in cycle (c_2+c_3), we need the distribution of the vehicle arrival times in this cycle. In a Poisson process, assuming n vehicles arrived in (0, t), the arrival time of these vehicles, $s_1, s_2 \ldots s_n$, are independently and uniformly distributed in this interval. Therefore the expected total delay is the area of the triangle in figure 1

$$\begin{aligned} D_3 &= \frac{1}{2}k_2*(c_2+c_3) \quad (7) \\ &= \frac{1}{2}k_2*(c_2+L+\frac{k_2/\mu_1}{1-\rho_1}) \end{aligned}$$

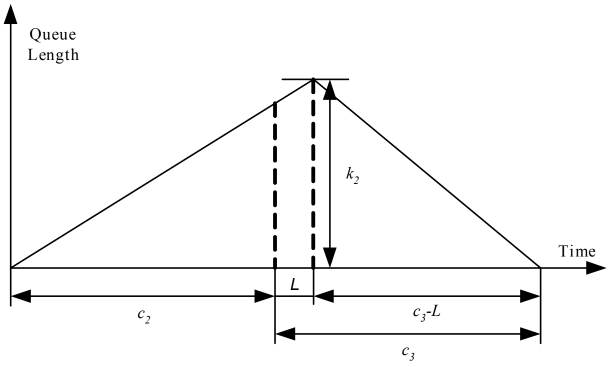


Fig. 1 Queue length curve in one cycle

The expectation of the average delay of W-E direction in (c_2+c_3), d_3 is

$$\begin{aligned} E(d_3) &= \sum_{k_2=1}^{\infty} P_{k_2}*D_3/S_3 \quad (8) \\ &= \frac{1}{2}[1-P(k_2=0)]*(c_2+L)*(1-\rho_1)+\frac{1}{2}\sum_{k_2=1}^{\infty}P_{k_2}*\frac{k_2}{\mu_1} \end{aligned}$$

Next step is calculating the pmf of X_3, the number of vehicles arrived in N-S direction in the time interval (c_3+L). The half cycle length c_3 is a discrete random variable, whose pmf is given. For any feasible k_3, we consider different (c_3+L). With their pmf, we can get the probability of exactly k_3 vehicles arrived during a specific (c_3+L). The summation all of these probabilities over all possible (c_3+L) gives the probability that there are exact k_3 vehicles arrived, no matter how long it is

$$\begin{aligned} P_{k_3} &= P(X_3=k_3) \\ &= \sum_{all(c_3+L)} P[X_3=k_3 \mid (c_3+L)]*P[(c_3+L)] \quad (9) \\ &= \sum_{k_2=0}^{\infty} P_{k_2}*P\{X_3=k_3 \mid [(c_3+L)=2L+\frac{k_2/\mu_1}{1-\rho_1}]\} \\ &= \sum_{k_2=0}^{\infty} P_{k_2}*\frac{[\lambda_2*(2L+\frac{k_2/\mu_1}{1-\rho_1})]^{k_3}}{k_3!}e^{-\lambda_2*(2L+\frac{k_2/\mu_1}{1-\rho_1})} \end{aligned}$$

The expectation of the green phase (c_4+L), which serves N-S direction, is

$$c_4-L=k_3*\frac{1/\mu_2}{1-\rho_2} \quad (10)$$

The number of vehicles served during this green phase is

$$S_4 = (c_4 - L) * \mu_2 = k_3 * \frac{1/\mu_2}{1-\rho_2} * u_2 = \frac{k_3}{1-\rho_2} \quad (11)$$

Similarly, the total delay of N-S direction in (c_3+c_4) is

$$D_4 = \frac{1}{2} k_3 * (c_3 + c_4) = \frac{1}{2} k_3 * (c_3 + L + \frac{k_3 / \mu_2}{1-\rho_2}) \quad (12)$$
$$= \frac{1}{2} k_3 * (\frac{k_2/\mu_1}{1-\rho_1} + \frac{k_3/\mu_2}{1-\rho_2} + 2L)$$

The expectation of the average delay (c_3+c_4), d_4 is

$$E(d_4) = \frac{1}{2}(1-\rho_2) * \quad (13)$$
$$\left\{ 2L * [1 - P(k_3 = 0)] + \sum_{k_2=1}^{\infty} P_{k_2} * \frac{1/\mu_1}{1-\rho_1} k_2 \right\} + \frac{1}{2} \sum_{k_3=1}^{\infty} P_{k_3} * \frac{k_3}{\mu_2}$$

Keep using this method on the following half cycles till reach a steady state, we can get the distributions of the following state variables of both directions.

- The pmf of total number of vehicles served in one cycle.
- The pmf of expected green phase length.
- The expectation of total delay and average delay in one cycle.

IV. FIXED TIMING SIGNAL CONTROL

In this section we consider the same intersection with fixed timing signal. The half cycle lengths of two directions are constant. As the signal setting is determined, arrival and departure processes of two directions are independent. We only analyze the N-S direction. The analysis of E-W direction is similar.

The vehicle arrival rates and service rates of two directions are same as those in section III. The time axis is divided into half cycles, each half cycle is composed of a constant time lost L plus a green phase. c_1 serves W-E direction and c_2 serves N-S direction. We have the optimal half cycle length for uniform arrival in (3). But this signal setting can't be used here directly since the cyclic capacity would be equal to the demand, which will make the M/D/1 system unstable. So we import a coefficient larger than 1 on c_1 and c_2, while keep the time lost L unchanged. The green phase length is increased, which makes the cyclic capacity greater than the traffic demand for both directions. The new signal setting is given in (14). If the coefficient is large, say greater than 2.5, the average delay begins to increase monotonously as the coefficient increases because too long green phase wastes the system capacity. We simply search the coefficient from 1.01 to 3.00 to find the optimal coefficient (here the optimal means minimum average delay at the steady state).

$$c_1 = \frac{1+\rho_1-\rho_2}{1-\rho_1-\rho_2} L * coeff \quad coeff > 1.0 \quad (14a)$$

$$c_2 = \frac{1-\rho_1+\rho_2}{1-\rho_1-\rho_2} L * coeff \quad coeff > 1.0 \quad (14b)$$

Assuming there is no residual queue at the beginning of the first half cycle c_1. Vehicle arrival follows Poisson distribution.

Define X_i as the number of arrived vehicles of N-S direction in ith cycle, and X_i' as the number of presented vehicles of N-S direction in ith cycle if there is residual queue from (i-1)th cycle (obviously we do not need to consider X_1'), we have

$$P_{k_i} = P(X_i = k_i) = \frac{[\lambda_2 * (c_1 + c_2)]^{k_i}}{k_i!} e^{-[\lambda_2 * (c_1 + c_2)]} \quad (15a)$$

Define $N = \lambda_2 * (c_1 + c_2)$, which is the expected number of arrived vehicles in one whole cycle, (15a) can be written as

$$P_{k_i} = P(X_i = k_i) = \frac{N^{k_i}}{k_i!} e^{-N} \quad (15b)$$

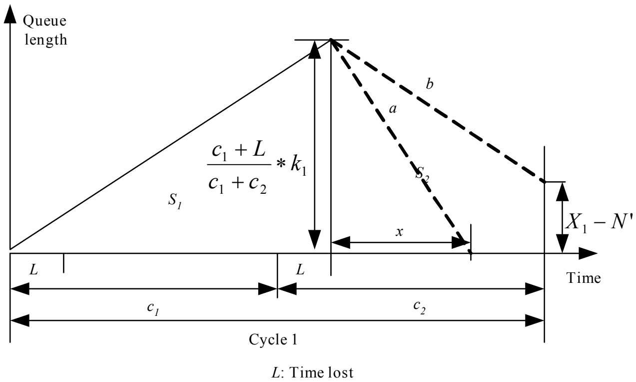
The cyclic capacity of this direction is

$$N' = \mu_2 * (c_2 - L) \quad (16)$$

There are two cases in cycle 1, which are represented by dash lines a and b: A) if $X_1 \le N'$, no residual queue would exist at the end of the cycle; B) if $X_1 > N'$, residual queue would exist.

The maximal queue occurs at the beginning of the green phase (shown in figure 2). Based on the distribution of the vehicle arrival (uniformly distributed if we have the total number of arrivals and the time interval of the arrival process), the expected maximal queue size in this cycle is

$$Q_{\max}^{(1)} = \frac{c_1 + L}{c_1 + c_2} * k_1 \quad (17)$$



L: Time lost
c: Half cycle

Fig. 2 Queue length curve of the first cycle

If case A happens, assuming it uses time x to clear queue in the first green phase. The intersection serves N-S direction with rate μ_2 in the interval [(c_1+L), (c_1+L+x)]. Because of the uniform distribution of the vehicle arrivals, the expected number of arrived vehicles from the beginning of cycle 1 to the time point at which queue is cleared is equal to the number of served vehicles in x

$$\frac{(c_1 + L) + x}{c_1 + c_2} * k_1 = \mu_2 * x \Rightarrow x = \frac{(c_1 + L) * k_1}{\mu_2 * (c_1 + c_2) - k_1} \quad (18)$$

In this situation, the total delay of this cycle is the area of the triangle in figure 2

$$D_1^A = \frac{k_1}{2}[c_1 + L + \frac{(c_1+L)*k_1}{\mu_2*(c_1+c_2)-k_1}]*\frac{c_1+L}{c_1+c_2} \quad (19)$$
$$= \frac{k_1*(c_1+L)^2}{2(c_1+c_2)}[1+\frac{k_1}{\mu_2*(c_1+c_2)-k_1}]$$

The average delay is

$$d_1^A = D_1^A / k_1 = \frac{(c_1+L)^2}{2(c_1+c_2)}[1+\frac{k_1}{\mu_2*(c_1+c_2)-k_1}] \quad (20)$$

In case B, residual queue exists at the end of the cycle with size of (X_1-N'), the queue length curve of the whole cycle is shown in figure 2, the total delay is the total area in the figure, including triangle S_1 and trapezium S_2.

The total delay is

$$D_1^B = S_1 + S_2$$
$$= \frac{k_1}{2}(c_1+L) + \frac{1}{2}(c_2-L)*(k_1-N') \quad (21)$$

The average delay of this case is

$$d_1^B = D_1^B / k_1 = \frac{1}{2}(c_1+L) + \frac{1}{2k_1}(c_2-L)*(k_1-N') \quad (22)$$

Define P_1^A as the probability of case A happens in cycle 1

$$P_1^A = P(R_1=0) = P(X_1 \le N') = \sum_{k_1=0}^{N'} \frac{N^{k_1}}{k_1!}e^{-N} \quad (23)$$

The residual queue R_1 has the following distribution

$$P(R_1 = i) = \frac{N^{N'+i}}{(N'+i)!}e^{-N} \quad for \quad i = 1,2,3\cdots \quad (24)$$

The average delay in this cycle has the expectation of

$$E(d_1) = \sum_{k_1=1}^{N'} P_{k_1} * d_1^A + \sum_{k_1=N'+1}^{\infty} P_{k_1} * d_1^B$$
$$= \sum_{k_1=1}^{N'} P_{k_1} * \frac{(c_1+L)^2}{2(c_1+c_2)} * [1+\frac{k_1}{\mu_2*(c_1+c_2)-k_1}] + \quad (25)$$
$$\sum_{k_1=N'+1}^{\infty} P_{k_1} * [\frac{1}{2}(c_1+L) + \frac{1}{2k_1}(c_2-L)*(k_1-N')]$$

If R_1=0, cycle 2 simply repeats cycle 1. Thus we only consider R_1>0 when analyze cycle 2. It is easy to get X_2'=R_1+X_2 with distribution of

$$P_{k_2'} = P(X_2' = k_2') = \sum_{i=1}^{k_2'}[P(R_1=i)*P(X_2 = k_2'-i)] \quad (26)$$
$$= \sum_{i=1}^{k_2'} \frac{N^{N'+i}}{(N'+i)!}e^{-N} * \frac{N^{(k_2'-i)}}{(k_2'-i)!}e^{-N}$$

The probability of $X_2' \le N'$ is

$$P(X_2' \le N') = \sum_{k_2'=1}^{N'}\sum_{i=1}^{k_2'}[P(R_1=i)*P(X_2=k_2'-i)] \quad (27)$$

The probability of no residual queue exists at the end of cycle 2, P_2^A, is composed of two parts: 1) no residual queue from cycle 1, and the total arrivals in this cycle is not greater than N'; 2) $X_2' \le N'$ happens. So the total probability is

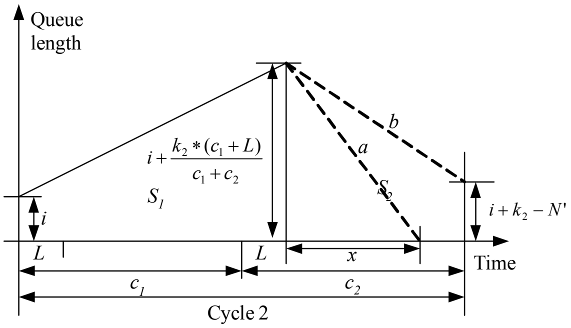
$$P_2^A = P(R_2=0) = P_1^A * (\sum_{k_2=0}^{N'} \frac{N^{k_2}}{k_2!}e^N) + P(X_2' \le N') \quad (28)$$

If a residual queue with size i exists at the end of cycle 2, there are two scenarios: 1) cycle 1 has no residual queue, exact N'+i vehicles arrived in this cycle, N' vehicles are served, i vehicles are left; 2) cycle 1 has residual queue with size j (j ranges from 1 to (N'+i)) and (N'+i-j) vehicles arrive in cycle 2, there are still (N'+i) vehicles present in this cycle. The probability of this happening is

$$P(R_2 = i) = P_1^A * P(X_2 = N'+i) + \sum_{j=1}^{N'+i}[P(R_1=j)*P(X_2=N'+i-j)] \quad (29)$$

To calculate the delay with residual queue from cycle 1, use i represent the size of residual queue of cycle 1 and k_2 represent number of vehicles arrive in cycle 2. The probability of this scenario is [(P(R_1=i)*P(X_2=k_2)]. The maximal queue $Q_{\max}^{(2)}$ occurs at the beginning of the green phase (see figure 3)

$$Q_{\max}^{(2)} = i + \frac{k_2*(c_1+L)}{c_1+c_2} \quad (30)$$



L: Time lost
c: Half cycle

Fig. 3 Queue length curve of the second cycle in case B

The dash lines a and b represent two sub-cases, residual queue exists or not at the end of cycle 2. Figure 3 shows the total delay in this cycle is composed of two areas, S_1 and S_2.

$$S_1 = \frac{1}{2}(c_1+L)*[2i+\frac{k_2*(c_1+L)}{c_1+c_2}] \quad (31)$$

To calculate the area of S_2, we consider two sub-cases.

A) If $X_2' \le N'$, no residual queue occurs at the end of cycle 2 (line a in figure 3), S_2 is a triangle. The expected busy period x in this green phase is

$$i + \frac{(c_1+L)+x}{c_1+c_2}*k_2 = \mu_2 * x \Rightarrow x = \frac{k_2*(c_1+L)+i*(c_1+c_2)}{\mu_2*(c_1+c_2)-k_2} \quad (32)$$

The area of S_2 in this sub-case, S_2^A, is

$$S_2^A = \frac{1}{2}x*Q_{\max}^{(2)} = \frac{[i*(c_1+c_2)+k_2*(c_1+L)]^2}{2(c_1+c_2)*[\mu_2*(c_1+c_2)-k_2]} \quad (33)$$

The total delay is

$$D_2^A = S_1 + S_2^A = \frac{1}{2}(c_1+L)*[2i+\frac{k_2*(c_1+L)}{c_1+c_2}] \quad (34)$$
$$+\frac{[i*(c_1+c_2)+k_2*(c_1+L)]^2}{2(c_1+c_2)*[\mu_2*(c_1+c_2)-k_2]}$$

The average delay is

$$d_2^A = D_2^A/(i+k_2) = D_2^A/k_2' \quad (35)$$

B) If $X_2' > N'$, residual queue exists at the end of cycle 2 (line b in figure 3), S_2 is a trapezium. The residual queue size is X_2'-N', the area of S_2 in this sub-case, S_2^B, is

$$S_2^B = \frac{1}{2}(c_2 - L) * [Q_{\max}^{(2)} + (i + k_2 - N')] \quad (36)$$

$$= \frac{1}{2}(c_2 - L) * [2i + k_2 * (1 + \frac{c_1 + L}{c_1 + c_2}) - N')]$$

The total delay is

$$D_2^B = S_1 + S_2^B = \frac{1}{2}(c_1 + L) * [2i + \frac{k_2 * (c_1 + L)}{c_1 + c_2}] \quad (37)$$

$$+ \frac{1}{2}(c_2 - L) * [2i + k_2 * (1 + \frac{c_1 + L}{c_1 + c_2}) - N')]$$

The average delay is

$$d_2^B = D_2^B \big/ (i + k_2) = D_2^B \big/ k_2' \quad (38)$$

The expected delay in cycle 2 is composed of three parts: A) no residual queue at the end of cycle 1, the expected delay is equal to the delay of cycle 1; B) there is residual queue at the end of cycle 1, and no residual queue occurs at the end of cycle 2; C) there is residual queue at the end of cycle 1, and residual queue occurs at the end of cycle 2

$$E(d_2) = P_1^A * E(d_1) + \sum_{k_2'=1}^{N'} \sum_{i=1}^{k_2'} [P(R_1 = i) * P(X_2 = k_2' - i) * d_2^A] \quad (39)$$

$$+ \sum_{k_2'=N'+1}^{\infty} \sum_{i=1}^{k_2'} [P(R_1 = i) * P(X_2 = k_2' - i) * d_2^B]$$

We get the expected total delay and average delay in cycle 2. Besides that we got the distribution of the residual queue in the end of cycle 2. Based on this, we can analyze cycle 3. The method can be continuously used on following cycles till reach the steady state of the system.

V. NUMERICAL METHOD RESULTS

In this section, the numerical method results are presented, and the average vehicular delays of two systems are compared. The results show that with Poisson arrival, the average vehicular delay can be reduced by using adaptive signal comparing to the fixed timing signal.

For both systems, we keep using the numerical methods until the steady state is reached. Then we calculate the weighted summation of the two directions' average delay based on their arrival rates, and use it as the vehicular delay of the intersection.

If vehicle arrival is distributed continuously and uniformly, the optimal signal setting and average delay can be calculated analytically. The result is presented for the comparison purpose.

Case 1: Symmetric intersection with equal arrival rates

In this case, the saturation flow rates of two directions are 0.5veh/sec, the arrival rates of two directions are equal, range from 0.05veh/sec to 0.2veh/sec. Time lost is 4 seconds.

Figure 4 shows the adaptive signal system always reduces the average vehicular delay compared to fixed timing signal system. Its performance is even better than the uniform arrival. That is because traffic volume in the latter case is continuous, which means delay always occurs. While with Poisson arrival, there is some possibility of no arrival during the red phase, which causes zero delay. The figure also shows lower the arrival rate (the possibility of no vehicle arrival during the red phase is higher), larger the difference between these two curves. As the arrival rate increases, they converge eventually. The results mean the overall performance of the adaptive signal control system with Poisson arrivals (very random) is slightly better than the system with uniform arrivals (very deterministic but continuous) and optimized fixed timing control. Figure 5 gives the percentage of average delay reduction with adaptive signal vs. fixed timing signal. As the degree of saturation of the intersection increases from 0.20 to 0.80, the adaptive signal can reduce the average delay from 35% to 60% compared to the fixed timing signal.

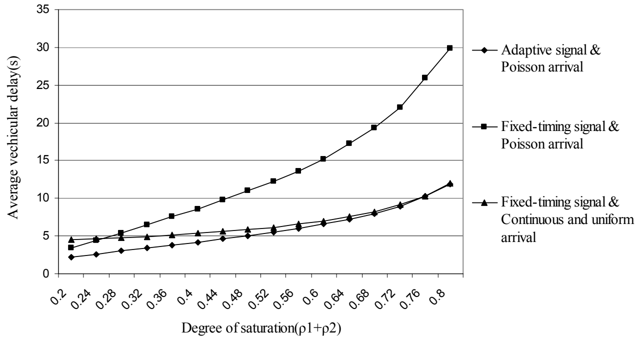


Fig. 4 Delay of symmetric intersection

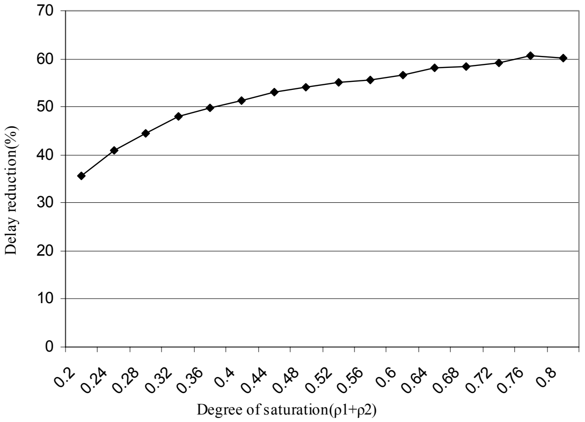


Fig. 5 Percentage of average delay reduction

Case 2: Asymmetric intersection with equal arrival rates

In this case, the saturation flow rate of N-S directions is 0.5veh/sec, that of E-W directions is 1.0veh/sec. The arrival rates of two directions are equal and increase from 0.05 to 0.27. Time lost is 4 seconds. The curves of this case are very similar as the first one.

From the results we can conclude no matter the saturation flow rates and arrival rates of two directions are symmetric or not, the adaptive signal system can always reduce the average delay comparing the fixed timing signal system, ranges approximately from 30% to 60% while the total degree of saturation ranges from 0.2 to 0.8.

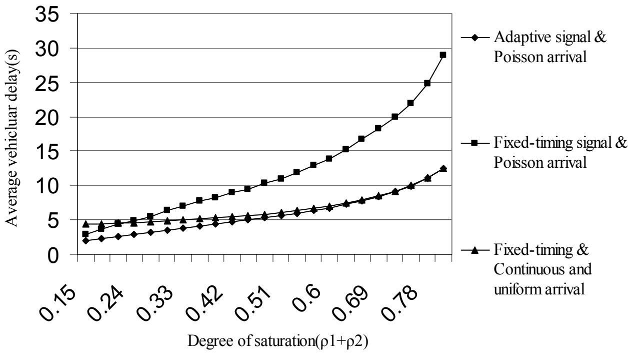


Fig. 6 Asymmetric intersection with equal arrival

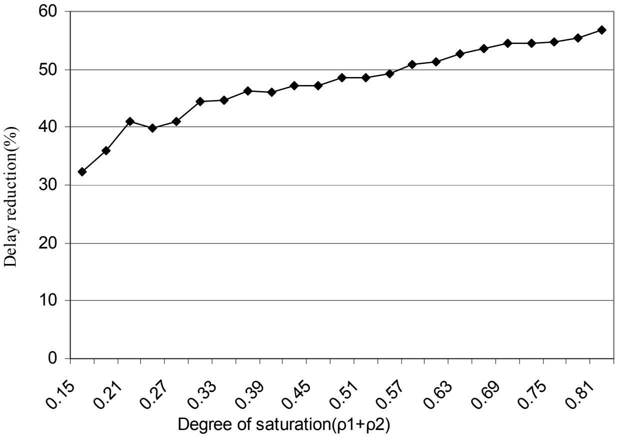


Fig. 7 Percentage of average delay reduction

VI. CONCLUSIONS AND FUTURE WORKS

Conclusions

This paper gives an analytical queuing model to analyze the queues of signalized intersections. Based on the queuing model, a numerical method is developed to calculate the queues and average delay of an isolated two-direction intersection. The results show overall performance of the adaptive signal control system with Poisson arrivals (very random) is slightly better than the system with continuous uniform arrivals (very deterministic). And the performance of the adaptive signal control system with Poisson arrivals is always better than the optimized fixed timing signal control system with Poisson arrivals.

Future works

Currently the mathematical model is an approximation of the RHODES system (developed at The University of Arizona). The difference is RHODES has the near-future information of vehicle arrivals because it has the vehicle detector data of the upstream intersections. Then it utilizes dynamic programming algorithm to optimize the traffic signals. Thus we can expect a better performance from the RHODES system.

In the near future, we plan to use mathematical language to build a model which has the exact behavior of RHODES system, and compare its performance with current adaptive control scheme.

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