The Application of the Two Levels of Priority Exhaustive Service Polling Control Theory in Intelligent Traffic System

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ABSTRACT

This paper presents a new use of two levels of priority exhaustive service polling control system in the intelligent traffic light control system. High priority will be set in main road and low priority be set in minor road. Compared to main road and minor road, because of the priority service policies the mean waiting time of the vehicles in the main road are shorter than the minor road’s, and the road capacity is improved. With the intelligent control, we can well solve the problem of traffic jams during different periods.

INTRODUCTION

Since 1864, traffic light\textsuperscript{[1]} has been the important guarantee of the traffic safety. Control the traffic in the intersection orderly and reasonably through the red, green, yellow light. Since the 20th century, the intelligent control technology rapid development. With the combination of a variety of hardware equipment, upgrading ordinary hardware equipment to intelligent control\textsuperscript{[2]} hardware devices. To achieve the machine equipment self-adjusting\textsuperscript{[3]} and adaptive control without human intervention. Intelligent traffic lights which combined ordinary traffic light to intelligent control, detects the arrival rate of vehicles and other indicators as a reference, to adjust the length of the passing time. Compared with ordinary traffic lights, intelligent traffic lights\textsuperscript{[4]} in addition to maintain traffic order and ensure the safety of pedestrians and vehicles, more is, control the length of the passing time under different conditions, intelligently, to improve the efficiency of traffic, easy traffic pressure.

This paper main to design the intelligent traffic light control system which base on the Two levels of priority exhaustive service polling control system\textsuperscript{[5]}. The arrival
rate of the vehicle as a reference, adjust the length of passing time through the exhaustive service poling model, to improve the efficiency of road. Through reasonable design, the system can realize control length of red, green, yellow light time reasonably and automatically with different arrival rate.

**SPECIFIC DESIGN**

In this paper, design of a intelligent traffic light control system can adjust the length of the passing time according to the vehicle's arrival rate. Specific design is install ground loop in all directions at the intersections to count the number of vehicles, and then enter data into the computer central control system to analyse the data and calculate the waiting time through the polling model with the current arrive rate. This result of the calculation been seem as the red light time in this direction.

In this system, two levels of priority exhaustive service polling control system are used in the main road and minor road in the intersection. On other word that the exhaustive service be used in main road and minor road with different arrive rate. According to the actual situation there are more vehicles in the main road, so the green light time were needed in main road.

**POLLING SYSTEM**

Polling system model consists of a server and N queues. The queues arrival process and the service time are random process in queuing mode.

The two levels of priority exhaustive service polling control system made up of a server, a centre queue $h$ and a ordinary queue $o$. The centre queue $h$ and ordinary queue $o$ adopt the rule which is exhaustive service. If the centre queue $h$ is not empty. The server services the centre queue $h$ with the exhaustive service at first, and then the server turn to services the ordinary queue $o$ with the exhaustive service. With the ordinary queue $o$ serviced completed the centre queue $h$ was the next serviced. This is the principle of two levels of priority exhaustive service polling control system making a distinction between the centre queue and the ordinary queue, the centre queue with high priority.

![Figure 1. Two levels of priority exhaustive service polling control system.](image)

**THE TWO LEVELS OF PRIORITY EXHAUSTIVE SERVICE POLLING MODEL OF INTELLIGENT TRAFFIC LIGHTS CONTROL SYSTEM**

This intelligent traffic lights control systems is seem as a double queues single server polling system, as shown in Figure 1. For practical purposes and supposes, the main road be seemed as a queue with the arrival rate of vehicles which is $\lambda$, so as the minor road. The $\beta$ means the service rate of the traffic light system. In this intelligent system $\beta$ is 0.1, mean there is one vehicle spend 1s to pass the waiting line. The
conversion rate of traffic light system is the length of yellow light time in this system, and there \( \gamma=1 \) means that there are 10s yellow light. The mean time delay and the mean queue length of vehicles in the main road and minor road figured out by the two levels of priority exhaustive service polling model.

Whenever the mean waiting time of vehicles were calculated greater than 60 seconds in the ordinary-time, we set the red light time in this road as 60 seconds. Whenever the mean waiting time of vehicles less than 60 seconds but longer than 10 seconds, the traffic lights would be controlled with the calculation results. Whenever the mean waiting time of vehicles were calculated greater than 90 seconds in the peak-time, we set the red light time as 90 seconds. Whenever the mean waiting time of vehicles less than 90 seconds but longer than 10 seconds, the traffic lights would be controlled with the calculation results.

The minimal red light time is 10 seconds.

**QUEUING MODEL AND OPERATION MODE**

There are 2 queues serviced by one traffic lights console in this intelligent traffic lights control system. Due to the queuing system is a solving process under the discrete time state, so the time axis is divided in time slot \( \tau \) (To make analysis into concise, we take \( \tau \) as the unit of time)

**Assumptions**

Each queues has the vehicles arrived into their queue space with independent and identically probability distribution at any time slot the distribution of probability generating function, the mean and variance are \( A(Z) \), \( \lambda = A'(1) \) and \( \delta^2 = A''(1) + \lambda - \lambda^2 \) respectively.

The random variable of query conversion time between the two queues is subject to a probability distribution which is mutually independent and identically distributed, the distribution of probability generating function, the mean and variance are \( R(Z) \), \( \gamma = R'(1) \) and \( \delta^2 = R''(1) + \gamma - \gamma^2 \) respectively.

The random variable of the time that each vehicles pass the crossroads is subject to a probability distribution which is mutually independent and identically distributed, the distribution of probability generating function, the mean and variance are \( B(Z) \), \( \beta = B'(1) \) and \( \delta^2 = B''(1) + \beta - \beta^2 \) respectively.

The queue space is big enough. The number of vehicles would not more than the queue space. For the vehicles that in the each queue, according to the principle of first-in-first-out.

**System Generation Function**

Define the variables \( G_h(z_1, z_2) \) and \( G_o(z_1, z_2) \) as the generation function of the vehicles queue in main road and in minor road respectively, then

\[
G_h(z_1, z_2) = R[A_h(z_1)A_o(z_2)]G_h(B_h[A_h(z_1)F_h(A_o(z_2))], z_2)
\]

\[
G_o(z_1, z_2) = G_o(z_1, B_o[A_o(z_1)F_o(A_o(Z_1))])
\]

(1)

(2)
Mean Queue Length

Define the variable \( g_o(j) \) as the number of vehicles in the minor road and main road waiting for passing the interaction \( (j=0, h) \) while there is the green light in the minor road and the variable \( g_h(j) \) as the number of vehicles in the minor road and main road waiting for passing the interaction \( (j=0, h) \) while there is the green light in the main road. Then:

\[
g_o(j) = \frac{r \lambda (1 - \rho)}{1 - \rho_h - \rho}
\]

\[
g_h(j) = \frac{r \lambda_h (1 - \rho_h)}{1 - \rho_h - \rho}
\]

Mean Waiting Time

Define the variables \( g_o(j,k) \) and \( g_h(j,k) \) as the second derivatives of generation functions, then,

\[
g_o(j,k) = \lim_{z_1 \to 1} \frac{\partial^2 G_o(z_1, z_k)}{\partial z_1 \partial z_k} \quad ; \quad j = o, h; k = o, h;
\]

\[
g_h(j,k) = \lim_{z_1 \to 1} \frac{\partial^2 G_h(z_1, z_k)}{\partial z_1 \partial z_k} \quad ; \quad j = o, h; k = o, h;
\]

Then,

\[
g_o(o) = \left( \frac{r(1 - \rho)}{1 - \rho_h - \rho} \right) + \left( \frac{r \lambda (1 - \rho)}{1 - \rho_h - \rho} \right) + \left( \frac{r \lambda_h (1 - \rho)}{1 - \rho_h - \rho} \right) + \left( \frac{r \lambda_h (1 - \rho)}{1 - \rho_h - \rho} \right)
\]

\[
g_h(h) = \left( \frac{r \lambda_h (1 - \rho)}{1 - \rho_h - \rho} \right) + \left( \frac{r \lambda_h (1 - \rho)}{1 - \rho_h - \rho} \right) + \left( \frac{r \lambda (1 - \rho)}{1 - \rho_h - \rho} \right) + \left( \frac{r \lambda_h (1 - \rho)}{1 - \rho_h - \rho} \right)
\]

Then, define the variable \( E(W_j) \) as mean waiting time of the vehicles in the main road and minor road \( (j=0, h) \). According to queue theory, the mean waiting time \( E(W_j) \) are expresses as follows

\[
E(W_j) = \frac{g_j(j,j)}{2} + A(1) - \frac{A(1)}{2 \lambda'} \left( B(1) \right);
\]

\[
\lambda' = \frac{\lambda h}{1 - \rho}
\]

THE SIMULATION

The simulation calculation and theoretical calculation take the same parameters. In the Fig.2, we set the load in the main road as the same with the load in the minor road to simulate the ordinary-time road condition, and the Y-axis is decrease into 10%. In the Fig.3, we set there is twice as much load in main road as in minor road to simulate the peak-time road condition, and the Y-axis is decrease into 10%.

In this system, there has a range which is stable region. The stable region means in this range of load, this system is working properly and steadily, would not occur traffic congestion and end up with the traffic system collapse. And there has a rule of the stable region is \( \rho_o + \rho_h < 1 \).
Because different time has different situation in the road, so there has different stable region in different time. With the simulation of ordinary-time (ρ_o=ρ_h) as the Fig.2, the stable region is ρ_o less than 0.3. With the simulate of peak-time (2ρ_o=ρ_h) as the Fig.3, the stable region is ρ_c less than 0.23.

Figure 2. The mean waiting time with the same load in the main road and minor road.

Figure 3. The mean waiting time with the twice of load in the main road as in the minor road.

Figure 4. Different mean waiting time with different load in main road.

We can find out that the mean waiting time of vehicles increase over the load. And because we take the priority algorithm in this model, it is apparently that the mean waiting time of vehicles in the main road is shorter than the minor road’s. So, the simulation calculation and theoretical calculation can prove that the high priority main road has the shorter mean waiting time of vehicles, although there is same load in the main road and the minor road.

Other shown in Fig.3 is that the higher load in the main road not only lead to the longer mean waiting time of vehicles in the main road but also lead to the longer mean waiting time of vehicles in the main road because in this model the main road must be serviced first. Example that when ρ_c =0.23, ρ_h =2* ρ_c =0.46, and ρ_c + ρ_h =0.69<1 is in the stable region, we can find out the mean waiting time of vehicles in main road is 34s and in the minor road is 88s. So we set 88s as the length of green light time in the main road and 34s as the length of green light time in the minor road to clear the road.

The mean waiting time of vehicles corresponds to load in the main road is the same, twice, and three times of the minor road’s be showed in the Fig.4. The higher load means the longer mean waiting time of vehicles and the faster growth.

CONCLUSIONS

Different road has different load. In order to improve the road capacity, an intelligent traffic light control system is necessary in today. Though the Two levels of priority exhaustive service polling control system we can find the relationship that the longer mean waiting time of vehicles because of the higher load. Compared to main road and minor road because of the two levels of priority exhaustive service
polling control system, the mean waiting time of vehicles of the vehicles in the main road are shorter than the minor road’s. Compute simulating result are consistent with theoretical analyses under the same load simulating the ordinary-time road condition, and twice times simulating the peak-time road condition. This results prove the analysis is right. Through above analysis, the intelligent traffic light control system which using Two levels of priority exhaustive service polling control system can do improve the road capacity by high priority main road and low priority minor road.

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