TCP, a traffic signal control algorithm based on knowledge and its simulation using RTE

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Abstract- **A traffic signal control algorithm based on knowledge of traffic engineers, named as TCP (Time to Change Phase) is put forward in this paper. The TCP algorithm is implemented and evaluated through microscopic traffic flow simulation software TSIS (Traffic Simulation Integrated System). The measurements of effectiveness (MOEs) of TCP, fixed-time and actuated control are compared with each other. The simulation results show that TCP algorithm gets better MOEs. Furthermore, when a parameter of TCP is optimized and even better MOEs are gotten. TCP algorithm is simple and practical and also has some characteristics of intelligence and robustness. How to improve TCP algorithm and develop traffic signal control system based on TCP algorithm are also outlined as future work.**

I. Introduction

With the rapid development of economics and society, vehicles increase more rapidly than the road capacity could hold, the urban traffic congestion become more and more serious, resulting in excess delay, reduced safety and increasing pollution. Intelligent Transportation Systems (ITS), which utilize advanced information, communication and control technology to alleviate traffic congestion, become the focus of current research on traffic and transportation engineering. ATCS (Advanced traffic control system) is one of the important components of ITS and is also an effective measure to lighten traffic congestion. ATCS have three layers of meaning: isolated intersection control, arterial traffic control and network traffic control. The isolated intersection control is the basis of the three layers, which can be expanded to construct ATCS. Isolated intersection control includes fixed-time control, actuated control, fuzzy control and so on.

The fixed-time control is often based on Webster formula [1]. The precondition of fixed-time control is to know the varying characteristics of traffic flow arriving at the intersection in advance. Although the variety of traffic flow has some similarity in macroscopic way, it has great randomness in microscopic characteristic, especially in a signal cycle. The fixed-time control is hard to adapt to the randomness of traffic flow, the effect of that is often not as good as the responsive control.

Actuated control [2], one kind of the responsive control, overcome the shortcoming of the fixed-time control, it can change the signal timing according to the random arrival of vehicles and have the potential to increase the capacity of an intersection and decrease the delay. However, the actuated control only considers the traffic flow in current phase, not taking the flow in antagonistic phases into account. So, actuated control has possibility to cause the long queued vehicles in other phases. With the progress of research, many researchers put forward many new traffic signal control algorithms, such as fuzzy control [3]. But, the advanced algorithms are often very complicated and have many parameters to adjust, so, it is difficult to use them in practice. A simple and effective traffic signal control algorithm is a challenge to traffic engineering community.

At the urban street in rush hour, a traffic engineer may observe the traffic flow at an intersection and determine when to change phase according to the queued vehicles in different phases. In general, an experienced traffic engineer could get the better control effect than some control algorithms and alleviate traffic congestion at intersection effectively. So, combining the traffic engineer's experience into control algorithm and optimize the parameters in the control algorithm could get better results. Based on this concept, the TCP algorithm is put forward, which is not dependent on the distribution of vehicles' arrival and the mathematical model of intersection control. RTE (run time extension) technology of TSIS is used to interface the TCP algorithms and CORSIM to validate the TCP algorithm.

II. TCP Algorithm

When a traffic engineer takes control of an intersection, his objective is to let as many vehicles as possible pass in current phase and not to make the queued vehicles in next phase too long. When a traffic engineer keep current phase green, he observes the vehicles in the next phase at the same

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time. When he find that the vehicles in current phase are so few or the vehicles in next phase is too many or the vehicles in next phase are evidently more than the vehicles in current phase, traffic engineer will change the current phase to next phase, otherwise, he will hold on the current phase.

In fact, the function of an experienced traffic engineer is just like a high intelligent traffic signal controller, the control effect of the traffic engineer is often better than some control algorithms. The traffic engineer's judgment is just based on his experience and wisdom without accurate quantitative concept in real-time control. To a traffic engineer, what is called very few vehicles in current phase, what is called too long queue in next phase, what is that vehicles in next phase is evidently more than the vehicles in current phase, are just his own feeling. TCP algorithm is put forward in this paper to embody the experience and wisdom of traffic engineer and microscopic traffic simulation software is used to evaluate the TCP algorithm. How to optimize the parameters of the algorithm is also considered.

According to the above-mentioned and take the minimal green time and maximal green time into account in engineering, the knowledge base of TCP algorithm is illustrated as Fig.1. From Fig. 1, it is easy to see that TCP algorithm have nothing to do with the geometrical shape of the intersection, the phase plan, the distribution of vehicles' arrival and the mathematical model of intersection control. It should be emphasized that when a phase is in green status, some lanes will get passage right at the same time. The total vehicles in all lanes are used in the TCP algorithm, not the vehicles in the key lane, so as to give all lanes an equal opportunity.

If the time of current phase is less than the minimal green time, **then** keep the current phase.

If the time of current phase is greater than the maximal green time, **then** change to next phase.

If the time of current phase is between minimal green time and maximal green time, and the vehicles in current phase are too few, **then** change to next phase.

If the time of current phase is between minimal green time and maximal green time, and the vehicles in next phase are too much, **then** change to next phase.

If the time of current phase is between minimal green time and maximal green time, and vehicles in next phase is much more than the vehicles in current phase, **then** change to next phase.

If in other conditions, **then** keep the current phase.

Fig.1 The knowledge base of TCP

III. TSIS RTE

Generally speaking, the effect of a traffic control algorithm can be validated by field test, macroscopic simulation and microscopic simulation. Field test can provide the most effective evidence, but it cost much time and money. The macroscopic simulation is easy to implement, however it simplifies the traffic flow phenomenon greatly, so, the reliability is not high. To use mature microscopic traffic flow simulation software to validate the traffic control algorithm is the most popular method in current research on traffic control, it have the advantages of the two-mentioned method and avoid their shortcomings.

To use microscopic traffic flow simulation software to validate traffic control algorithm, it is necessary to know the interface between simulation software and outer software. RTE (run-time extension) is the interface of TSIS (Traffic Simulation Integrated System) with other languages, such as Visual C++ and FORTRAN. By using RTE, many adaptive traffic control algorithms can be tested in simulation software first before implementation, so as to ensure it will have good effect in practical engineering. VFC-OPAC system and REHODES system are successful examples using RTE [4]. RTE will also be used to interface TCP algorithm and CORSIM and MOEs of other control algorithms are compared each other.

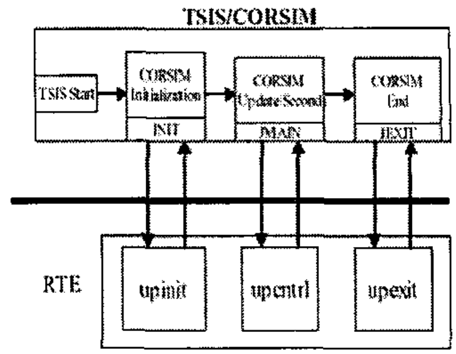

Fig.2 The data exchange process between RTE.dll and TSIS 5.0

The important step of interface between TSIS and TCP is to implement the traffic signal control algorithm in RTE.dll. The process of data exchange between RTE.dll and Corsim.dll is illustrated in Fig.2. Upinit, Upctrnl, Upexit functions are the three important functions in RTE.dll, which correspond to the threes functions (INIT, JMAIN, JEXIT) in Corsim.dll accordingly.

Upinit function read simulation file so as to create link object, node object, detector object and so on. Upcntrl function is the key function to realize the traffic control algorithm; the user-designed traffic control algorithm will be implemented in this function. In the simulation process, RTE.dll exchange data with Corsim.dll once a second, and send the signal control parameters to CORSIM based on the detector data and user-designed traffic control algorithm. Upexit function is evoked at the end of simulation to delete all the traffic network objects and quit the RTE.dll [5].

IV. Simulation Case

A. Intersection

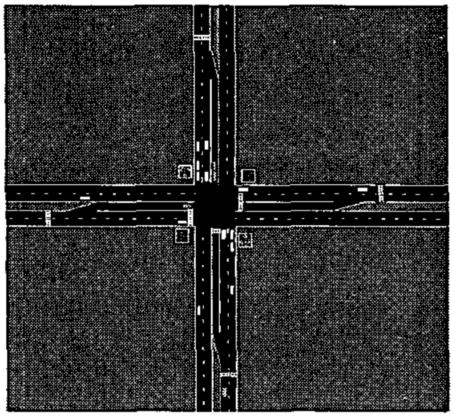

Fig.3 The simulation case in TSIS

The intersection is a simple two-phase intersection and the simulation case by TSIS is illustrated in Fig.3, displaying the shape of intersection and the location of detectors. The first phase is North-South and the second one is East-West.

B. Traffic flow

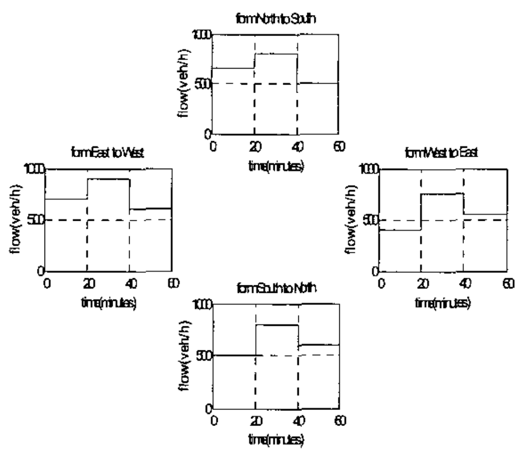

Fig.4 The traffic flow of the four approaches of the intersection

The variation of traffic flow in four approaches are shown in Fig.4 The curves in Fig.4 show that traffic flow in four approaches vary a whole process, from light to heavy and then from heavy to light. However, the change of traffic flow of different approaches is independent each other and the distribution of traffic flow is all normal distribution. The turning percentage of traffic flow in the intersection can be seen in Table1.

C. Setting of different control algorithms

According to Webster formula, the cycle of fixed-time control is 60 seconds; the green time of phase one is 24 second; the green time of phase two is 26 seconds. The yellow time is 3s and the all red time is 2s.

TABLE I
THE TURNING PERCENTAGE OF DIFFERENT APPROACHES IN THE INTERSECTION

PERCENTAGE APPROACHES	LEFT	THROUGH	RIGHT
FROM SOUTH TO NORTH	10	70	20
FROM EAST TO WEST	15	62	23
FROM WEST TO EAST	12	63	25
FROM NORTH TO SOUTH	20	65	15

The control strategy of actuated control is full-actuated control. The loop detector is 40 feet from the stop bar, and the width of detection is 6 feet. Table 2 displays the parameters' setting of actuated control.

TABLE 2
THE PARAMETERS' SETTING OF ACTUATED CONTROL

PARAMETER	VALUE
MINGREENTIME	10S
MAXGREENTIME	40S
YELLOW	3S
ALL RED	2S
EXTENSION TIME	3S

TCP algorithm needs two detectors in one approach; so 8 detectors are used, as in Fig.1. The vehicles in an approach are given by:

appVehicle(t)=inVehicle(t)-outVehicle(t)+origVehicle (1)

Where, inVehicle (t) are the number of vehicles entering into the detection zone at time t, which is detected by the first detector in the approach. outVehicle (t) are the number of vehicles exiting from the detection zone at time t, which is detected by the second detector near the stop line in the approach. origVehicle is the number of vehicles in the detection zone before simulation. All of these variables can be provided by CORSIM in the simulation once a second.

TABLE 3
THE PARAMETERS' SETTING OF TCP ALGORITHM

PARAMETER	VALUE
MINGREENTIME	10s
MAXGREENTIME	40s
MINVEHCP	2
MAXVEHNP	40
MAXVEHDIFF	3.0

Table 3 displays the parameters' setting of TCP algorithm. The length of detection zone is 220 feet. The minimal vehicles in the current phase are defined as minVehCP; maxVehNP represents the maximal vehicles in the next phase. The maximal ratio of vehicles in current phase to vehicles in next phase is defined as maxVehDiff and if the real vehicle ration is greater than it, it is time to change phase.

V. Simulation Results and its Analysis

This section will compare the control effect among TCP algorithm, fixed-time control and actuated control. The compared MOEs include the total time, move time, delay time and mean speed of all vehicles during the simulation. Table 4 displays the comparative results of the three kinds of control algorithms.

TABLE 4
COMPARATIVE RESULTS OF CONTROL EFFECT OF TCP, FIXED-TIME CONTROL AND ACTUATED CONTROL

MOEs / ALGORITHM	TT	MT	DT	MS
FIXED-TIME CONTROL	44.85	33.42	11.43	20.72
ACTUATED CONTROL	41.94	32.39	9.54	23.21
TCP ALGORITHM	39.11	31.44	7.67	24.39

TT=Total Time, MT=Move Time, DT=Deley Time, MS=Mean Speed.
The units of TT, MT and DT is Vehicle*hours.
The Unit of MS is mile/hour.

From Table 4, it is easy to see that TCP algorithm gets the best MOEs, actuated control ranks the second, the fixed-time control the worst; because the total time of TCP is the smallest and the mean speed is the highest. Compared to fixed-time control, the total time of TCP algorithm decrease 12.8%, the delay time decrease 32.9%, move time decrease 5.9%, and the mean speed increase 17.7%. Due to the fixed-timing, the fixed-time control cannot adapt to the change of traffic flow, so the control effect is the worst. Compared to the actuated control, TCP algorithm also gets little better MOEs as well: move time decrease 6.7%, mean speed increase 4.8%, which is possible due to that TCP algorithm not only consider the vehicles in current phase like actuated control, but also take the vehicles in next phase into account.

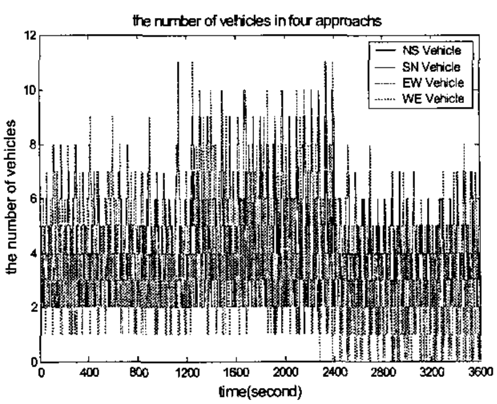

Fig.5 The number of vehicles in four approaches

Fig. 5 illustrates the number of vehicles in detection zone of four approaches gotten by TCP algorithm. From Fig.5, it is easy to see that the number of vehicles in any approach reflects the repeating process of aggregation and dispersion. The different curves have little difference with each other. The maximal vehicles in four approaches are 10,11,9,10 and the minimal vehicles are 2,3,1,0, respectively. In the middle stage of simulation, traffic flow is high; so, the curve is much higher than that of other stages. These show that the TCP algorithm takes the vehicles in current phase and the vehicles in next phase into account comprehensively, so the green time of phase is utilized fully.

Although TCP algorithm gets better results than fixed-time control and actuated control, the setting of parameters' of TCP algorithm is mainly dependent on experience and not optimized. As the limit to the length of the paper, here we just discuss how the most important parameter maxVehDiff influences the control effect. Fig.6 displays the relationship between total time and maxVehDiff.

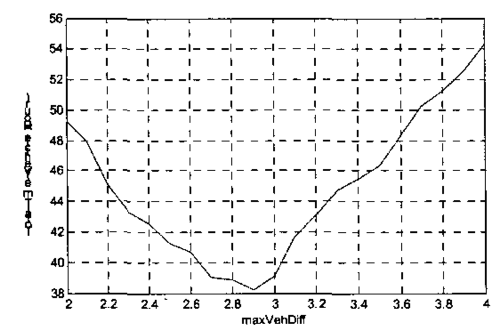

Fig.6 The relationship between maxVehDiff and TotalTime

From Fig.6, we can see that different maxVehDiff have different control results. When maxVehDiff is equal to 2.8, the Total Time reaches the minimal value. To increase or decrease maxVehDiff from the 2.8, the Total Time will increase. The possible reason about it is that if the maxVehDiff is too small, the phase change frequently, the effective green time will decrease more; if the maxVehDiff is too large, the waiting time in the antagonistic phase will increase greatly.

VI. Conclusion

The distinguished advantage of TCP algorithm is simple and practicable. Compared to fixed-time control, it can adapt to the stochastic change of traffic flow. Compare to the actuated control, it take the vehicles in current phase and the vehicles in next phase into account comprehensively. Compare to other complicated algorithms, it is simple and easy to implement. TCP algorithm is a kind of intelligent algorithm, as it is based on the experience of traffic engineering. Furthermore, there are only a few parameters which TCP algorithm is dependent on. Beside, the MOEs of TCP are relatively stable when parameters in TCP vary in a certain range according to our tests. Therefore, TCP algorithm demonstrated some robustness.

Although TCP algorithm show some potential in traffic signal control, due to the paper limitation, the comparison with other control algorithms is not sufficient. More and other situations and other traffic demand patterns should be simulated in the future to come to a better conclusion, especially when the assumptions for the other control algorithms are changed or optimized. In this paper, we just optimize a parameter maxVehDiff of TCP algorithm with an off-line optimization; the on-line optimization algorithm will be more useful and the simulation case is a simple two-phase control in this paper. We will extend TCP algorithm to multi-phase control with on-line optimization in the future. TCP algorithm is just a block to build the simple and intelligent traffic control system, so, to implement it into an agent based controller and study coordinated algorithm with other intersection controllers is the future direction of our research.

However, TCP algorithm needs more detectors to get the accurate number of vehicles in the detection zone, which require more on the accuracy of the detectors and the cost of the system. Finally, the TCP relays on the reliabilities of the detention, it is very important to get right experience and knowledge.

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