Mutual Exclusion Algorithm for Real-time Traffic Dispatching Based on Game Theory

Jianchun Jiang1, Fei Peng1, a, Bowen Zhao2

1 Chongqing University of Posts and Telecommunications, School of Software Engineering Nan'an District, Chongqing, P. R. China
2 Chongqing University of Posts and Telecommunications, Nan'an District, Chongqing, P. R. China

a 1018601787@qq.com

Abstract. With the rapid increase of vehicles, real-time dynamic dispatch is an important means to alleviate traffic congestion. Game theory-based real-time vehicle scheduling algorithms are often used for dynamic adjustments, but traditional algorithms only switch signal phases for fixed phases during dynamic adjustment scheduling, and cannot achieve the comprehensiveness of real-time scheduling; or phases with large differences in traffic flow when setting the duration, the reasonable waiting time for the smaller traffic phase are not considered. In order to solve the real-time dynamic adjustment of signal lights, an improved algorithm based on game theory is designed to control the signal switch in the game mode, and the waiting time of vehicles at traffic intersections can be reduced by adding parameter values of lane waiting time changes. Through experimental comparison, the algorithm reduces the vehicle stay by 3.4% and the waiting time by 4.4% compared with the fuzzy algorithm of the polling mechanism.

1. Introduction
With the acceleration of China’s urbanization process, the number of cars is increasing rapidly, resulting in serious traffic congestion and environmental pollution and huge costs, and also bringing severe challenges to the transportation system. Traditional fixed traffic control has been unable to meet the needs at present. The urban traffic system is a large non-linear, random system, and a specific predefined traffic signal plan cannot effectively adapt to all real-time traffic conditions. Therefore, real-time and dynamic traffic scheduling is crucial in solving the current problems.

2. Research Status
At present, there is extensive research on adaptive control of intersection signals. Literature [1] A. Stevanovic compares the InSync adaptive traffic control system with TOD under daily traffic conditions and special sudden traffic conditions. InSync is better than TOD signal timing plan. Literature [2] Lubing Li based on the cumulative queuing regime, this study first extends the delay models, which are usually formulated for isolated intersections, to the case of coordinated intersections by explicitly incorporating the effects of residual queue and signal offset, the gradient solution algorithm based on PCR adaptively adjusted the offset to solve the random problem. Literature [3] deals with the saturated flow of roads during congestion, continuously estimates error terms through a fault detection algorithm,
and then controls it with a reconstruction regulator to reduce the number of vehicles waiting at intersections. Literature [4] proposed a method of combining ramp control and coordinated control of urban expressways to obtain the optimal signal control through an improved particle swarm algorithm. Literature [5] is based on the Gaia method, and each intersection is a multi-agent system that manages its own traffic signal plan. Literature [6] established a lane variable cumulative accumulation framework and lane control delay model based on group variables. Aiming at the problem of group-based signal timing optimization in adaptive traffic control systems, a rolling horizon-based delay optimization method for lane control to improve the accuracy of predictions. Literature [7] proposed a general continuous queuing time model, which the Proximal/gradient method to calculate the Nash equilibrium point and obtains the average optimal strategy.

The literature [8] game theory studies the cooperation and competition among decision makers, and is also involved in the signal control of intersections. Literature [9] models the signal control in four stages, and the Nash equalization strategy obtains the optimal control strategy and the signal duration of the variable phase. [10] A four-phase fixed-period single intersection was used as the research object. The store-and-forward method was used to model the queue length of vehicles in each phase. The traffic flow in each phase was used as the player. And the Shapley estimation algorithm to find the green light duration.

The above algorithms can improve traffic efficiency. However, some of these algorithms are researched between fixed phases and cannot perform real-time dynamic adjustments to ensure the maximum of intersection resources; or the irrational setting of the length of traffic lights, which only considers the situation of fixed signal cycles. When the phase traffic flow is uneven, excessive waiting of vehicles and too hungry lanes cause waste of transportation resources.

Aiming at the above problems, this paper a game theory adaptive real-time traffic dispatching method, which can solve the problems of signal changes at traffic intersections that cannot be adjusted in real time according to the actual situation and excessive waiting of vehicles under different traffic flow conditions. The method uses the traffic flow of each phase to play a game and adds the waiting time parameter to calculate the priority to obtain the optimal control strategy. The signal duration is set according to the minimum traffic flow direction in the strategy to reduce the waiting time of vehicles at traffic intersections and improve traffic effectiveness.

3. Algorithm model
The main idea of this algorithm is based on the mutually exclusive algorithm of game theory, and calculates the priority level by obtaining the number of vehicles on the lane to realize the phase selection. This algorithm notice that when a certain phase is at the peak time, there are a large number of vehicles, which makes it in the passing phase for a long time, which causes a long stay of vehicles in other directions. By adding the waiting time control parameter when calculating the lane priority, it is ensured that when the traffic volume in a certain direction is large, the lane direction with a small traffic volume will not be in a waiting state for a long time.

3.1. Game theory model
Game theory: In a game of n participants, S_i is the set of strategies that participant i can choose, and u is the return function.

3.2. Intersection general model analysis
In this model, vehicles are mainly used as traffic objects, and the traffic object models at intersections are studied. As shown in Figure 1, there are two left-turn and straight-forward traffic flows in each of the four directions of the intersection: southeast, northwest, and northwest. i indicates the direction of the lane vehicle. In this article, vehicles turning are free and will not cross paths with vehicles traveling in other directions, so it is not considered.

In this model game, participants pursue their own interests while participating in the game in the form of alliances and cooperation, so as to maximize their own and cooperation benefits. As shown in
Figure 1, if there is no collision in the direction of vehicle traffic, according to the analysis, a maximum of two traffic directions are allowed at a time. A parameter $k$ is set, which indicates the mutually exclusive relationship between the 8 intersections; the direction of the traffic flow is controlled by setting the size of the parameter $k$.

This model mainly solves the problem during the traffic dispatching process, the signal lights can ensure real-time dynamic adjustment without collision.

![Intersection model](image)

Figure 1. Intersection model

### 3.3. Improved game theory algorithm model

The above model solves the problem about the rationality of signal phase switching in traffic dispatching, but it is also necessary to calculate the direction of signal switching phase and the setting of the duration of the signal.

Therefore, in order to solve this problem, this model optimizes the game theory algorithm, and calculates the signal phase at the next moment by comparing the returns after the return game. The model first needs to calculate the priority of each phase. In order to cut the waiting time in a situation of a small traffic flow, a waiting time parameter is added to the priority calculation formula to ensure the vehicle’s passing efficiency.

Since two lane vehicles are allowed to pass at the same time, it can be understood in the model. There are 2 participants, each participant has 8 strategies, and the optimal solution is obtained through the game. Then the priority of each traffic flow direction is the benefit value of the participants in the competition.

Priority calculation formula:

$$P(i) = \sum_{n=1}^{q} t(i) + kq(i)$$  \hspace{1cm} (1)
In the formula, \( P(i) \) is the priority level of the corresponding lane, \( t(i) \) is the waiting time change parameter of the corresponding lane vehicle, \( k \) is the coefficient, \( q(i) \) is the number of vehicles in the corresponding lane.

In order to ensure the maximum benefit of the traffic dispatch at the intersection, the value of the game between the two participants under different strategies is calculated \( u_n \).

\[
u_n = k(a, b)P(a)P(b)\]  \hspace{1cm} (2)

\( K \) is the mutually exclusive relationship between lanes \( a \) and \( b \).

According to (1) and (2), comparing the magnitude of the benefit value, we can get the allowed lane direction of the signal light at the next moment.

Calculate the number of vehicles crossing the lane \( q_{pass} \) and the number of vehicles staying at the intersection \( q_{stop} \):

\[
q_{pass} = q_{pass}(a) + q_{pass}(b) \]  \hspace{1cm} (3)

\[
q_{stop} = \sum_{i=1}^{8} q(i) - q_{pass} \]  \hspace{1cm} (4)

At the same time, the vehicle delay calculation formula is:

\[
d_x = |t_x - t_0| \]  \hspace{1cm} (5)

\[
d_i = \sum_{x=1}^{8} d_x \]  \hspace{1cm} (6)

In the formula, \( d_x \) is the time required for the \( x \)th car to pass the intersection; \( t_0 \) is the time required for the free flow to pass the intersection; \( t_x \) is the actual time for the \( x \)th car to pass the intersection; \( d_i \) is the \( i \)th lane Total delay.

According to (5) and (6), the total vehicle delay time \( d \) at the intersection can be calculated:

\[
d = \sum_{i=1}^{8} \sum_{x=1}^{8} t_x(i) - t_0(i) \]  \hspace{1cm} (7)

After determining the passing phase, set the green time based on the number of vehicles in the passing phase. If the green light time is too long, there will be some time left even after all the vehicles pass, if the green light time is too short, only a few of them can pass.

The setting of the traffic lights in this article is dynamic. The minimum green time is 15 seconds and the maximum is 60 seconds, \( T_{green} = T \). The value of \( T \) is determined based on the number of vehicles in phases \( a \) and \( b \).

\[
q_{green} = n \max\{ q(a), q(b) \} \]  \hspace{1cm} (8)
In the formula, \( n \) represents a coefficient, and the minimum traffic volume is obtained by comparing the traffic volume between two phases, and the value of \( T \) represents the time required to pass the intersection under the condition of free flow of the \( q_{\text{green}} \)th vehicle. By setting \( T_{\text{green}} \), even when the traffic flow in one direction is large, the traffic flow in other phases is small. By formula (8), set the traffic light time based on the minimum traffic flow in the traffic direction. Set the number, the next time the traffic lights change, because the direction of the larger traffic flow is still too high, it will continue to be a green light to ensure the dynamic adjustment of other non-mutually exclusive phases.

4. Algorithm verification

4.1. Verify content
The algorithm simulation in this paper is mainly divided into two parts. First, the number of vehicles is used to calculate the priority level, and the profit function is further calculated to obtain the allowed phase. And set the green time by the number of vehicles. By comparing with the fixed timing scheme and the current [11] algorithm, vehicles at right turn and U-turn are not considered. The comparison parameters include the number of parked vehicles, the cumulative number of parked vehicles at the intersection, and waiting time. The simulation demonstration is realized by a computer program.

4.2. Verification conditions and results
1) Heavy traffic on straight: Suppose there is a left-turn, straight lane in each direction of the intersection. The speed is 60km/h, and the time for each vehicle to cross the intersection is 2 seconds. The simulation time is 60 times of traffic light change. Traffic flow of straight and left turns 3:1, the average traffic volume at the intersection is 3600 vehicles/hour. The simulation results recorded 60 traffic light changes.

![Figure 2. Cumulative number of waiting vehicles when traffic is going straight](image-url)
It can be seen from Figure 2 that after the improved game theory algorithm model is adopted, the total number of vehicles stopped at the traffic intersection is reduced by 24.2%. In Figure 3, the waiting time of vehicles at the intersection changes with the number of changes. The total waiting time of the vehicle is reduced by 28.6%, which is less than the time in the fixed-time model, and the waiting time of the vehicle has less fluctuation, which improves the stability of traffic flow.

2) A large amount of traffic in one direction: Assume that the average traffic flow in a single direction at an intersection is 1,000 vehicles/hour, and the average traffic flow in other directions is 300 vehicles/hour. The time for each vehicle to pass through the intersection is 2 seconds, the speed is 60km/h, and the simulation time is Traffic lights change 60 times. The simulation results recorded 60 traffic light changes.

Figure 3. Cumulative waiting time when traffic is going straight

Figure 4. Cumulative waiting time when traffic is a large amount of direct traffic
In the case of a large amount of direct traffic at the intersection, there is a comparison of the optimized game dispatching game theory algorithm and fixed timing. In Figure 4, the total waiting time of the algorithm is reduced by 9.9% compared with the fixed model. Due to the large traffic volume in a single direction in Figure 5, the total number of waiting vehicles has been reduced by 7.8%.

The fixed model cannot adaptively adjust the phase according to the size of the traffic flow in the traffic dispatching, which causes the vehicle waiting time at the intersection to be too long. This algorithm model is better than the fixed model. It can dynamically adjust in real-time in the traffic dispatching, and can reasonably set the traffic timing, which effectively improves the traffic efficiency and the stability of the traffic flow.

3) Comparison of other algorithms: Assume that at the intersection, the average traffic volume in each direction is 600 vehicles/hour. The time for each vehicle to pass through the intersection is 2 seconds, the speed is 60km/h, and the simulation time is 60 times for traffic lights. Simulation results recorded 60 traffic light changes.
Figure 6 and figure 7 compare the simulation with the current algorithm when the traffic flow at the intersection is uniform. As the number of changes in the signal lights increases, the number of vehicles at the intersection decreases by 3.4% and the average waiting time at the intersection decreases by 4.4%. Because only four phase models can be compared to obtain the best strategy, and this algorithm model has a certain degree of adaptability, the phase can be switched according to the game result of the phase priority of the traffic intersection. The algorithm model is better in this situation.
5. Summary
The signal lights at intersections can be controlled thanks to the feasible use of the improved game theory algorithm in this paper. It has certain advantages such as real-time performance and high traffic efficiency. The experimental results show that the waiting time of vehicles is relatively short even at peak hours. Traffic congestion is reduced significantly, and to a certain extent, the green light of a certain phase is allowed by the size of the priority, so that vehicles in other directions will not wait too long. Compared with the current algorithm, it also has certain advantages.

In the future, this algorithm will be further extended, such as the green wave band algorithm, to further study and research.

Acknowledgments
This work was supported by the National Science and Technology major projects under Grant 2018ZX03001023-006.

References
[1] A. Stevanovic, I. Dakic and M. Zlatkovic, “Comparison of adaptive traffic control benefits for recurring and non-recurring traffic conditions,” in IET Intelligent Transport Systems, vol. 11, no. 3, pp. 142 - 151, 4 2017.
[2] Lubing Li, Wei Huang, Hong K, Lo. “Adaptive coordinated traffic control for stochastic demand,” Transportation Research Part C: Emerging Technologies, vol. 88, 2018, pp. 31 - 51.
[3] Varga, Istvan, “A congestion detection based traffic control for signalized intersection,” Periodica Polytechnica-Civil Engineering, Vol. 62, no. 2, pp. 398 - 403, 2018.
[4] Yaying Zhang, Qunhao Ni, “A coordinated traffic control on urban expressways with modified particle swarm optimization,” Ksce Journal of Civil Engineering. vol. 21, pp. 501-511, Feb. 2017.
[5] C. Vilarinho, J. P. Tavares and R. J. F. Rossetti, “Design of a Multiagent System for Real-Time Traffic Control,” in IEEE Intelligent Systems, vol. 31, no. 4, pp. 68 - 80, July-Aug. 2016.
[6] Lee Senughyeon, Wong S.C, “Group-based approach to predictive delay model based on incremental queue accumulations for adaptive traffic control systems,” Transportation Research Part B: Methodological. Vol. 98, pp. 1 - 20, Apr. 2017.
[7] Y. Wang, D. Wang, S. Jin, N. Xiao, Y. Li and E. Frazzoli, "Iterative Tuning With Reactive Compensation for Urban Traffic Signal Control," in IEEE Transactions on Control Systems Technology, vol. 25, no. 6, pp. 2047-2059, Nov. 2017.
[8] X. He, H. Dai, P. Ning and R. Dutta, "Zero-determinant Strategies for Multi-player Multi-action Iterated Games," in IEEE Signal Processing Letters, vol. 23, no. 3, pp. 311-315, March 2016.
[9] RC. Gonzalez, JB. Clempner, “Solving traffic queues at controlled-signalized intersections in continuous-time Markov games,” Mathematics and Computers in Simulation, Vol. 166, pp. 283 - 297, Dec. 2019.
[10] W. Mingyue and Y. Chenkun, "Optimal signal timing strategy of the isolated intersection based on cooperative game," The 27th Chinese Control and Decision Conference (2015 CCDC), Qingdao, 2015, pp. 5128 - 5133.
[11] W. Yi-Fei and G. Zheng, “Research on Polling Based Traffic signal Control Strategy with Fuzzy Control,” 2018 IEEE 4th International Conference on Computer and Communications (ICCC), Chengdu, China, 2018, pp. 500 - 504.