Adaptive Traffic Signal Coordinated Timing Decision for Adjacent Intersections with Chicken Game

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Abstract. Adaptive traffic signal timing decision is a promising technique to alleviate traffic congestion which is an issue in every major city. An interesting problem is to study the traffic signal timing decision on an intersection, that is an important aspect of the urban traffic control system. According to the mutual relevance of traffic flow between intersections and the theoretical framework of chicken game, traffic signal timing decision model based on chicken game was proposed for two adjacent intersections. Each intersection was defined as a game player and the queue length of the whole intersection was regarded as payoff function. Nash equilibrium of mixed strategies was obtained based on the chicken game model which belongs to a non-cooperative game, so the state of signal light in next game-cycle can be on-line adjusted. The digital characteristics and effectiveness of the proposed method was analyzed. Simulation results showed that the game-based method substantially outperforms the other non-coordinated method like fixed timing control. The queue length of the intersection and the total vehicle travel time and topping number at each section can be effectively improved using the proposed algorithm.

Keywords: Adaptive traffic signal timing · Intersection · Chicken game
Decision

1 Introduction

Adaptive traffic signal timing decision is a complex decision making task in an inherently non-static environment. Optimized traffic control systems directly contribute to travel time reduction, savings in fuel consumptions, and vehicular emissions reduction. Clearly there is a need for developing efficient algorithms for coordinating traffic signals to improve the operations of traffic systems.

The majority of these methods are based on either neuro-fuzzy or Multi-Objective Genetic Algorithms. However, as mentioned in Faye et al. (2012), the use of fuzzy logic is not sufficient to represent the realtime traffic uncertainties. Also, neural networks and genetic algorithms require many computations and their parameters are difficult to be determined. In addition, as mentioned in Liu (2007), traffic signal control methods based on fuzzy logic are more suitable to control traffic at an isolated

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intersection. Also, evolutionary algorithms such as genetic algorithms will spend huge time to converge to the optimal traffic signal decision for large scale networks.

Some efforts have been made to develop real-time or data-driven offset optimization models to achieve coordination between different intersections. Zheng et al. (2017) built an arterial traffic coordinated control model based on section speed in a range. It is on the basis of the traditional mixed integer linear programming (MILP) model and the analysis of the influence and requirements of minimum speed and maximum speed on bandwidth. These models focus either on progression quality or green time occupancy and most of them are designed to improve the efficiency of one main direction.

Transportation researchers have a long history in using Game theory for the development of User Equilibrium models in traffic assignment. Recently, the game theoretic approach has been gradually applied in different traffic areas. At present, the application of game theory in the field of traffic mostly concentrated in the traffic guidance and traffic management. Purohit and Mantri (2013) utilized the game theory in a dynamic transportation environment to control the traffic flow and improve the disaster management for both non-cooperative and cooperative problems. The goal of the research is to select the optimal path for the vehicles to optimize the queuing result. Labbi et al. (2017) modeled a simplified subset of the general phenomena of multipath traffic control that can be described using some of the tools provided by notions imported from Game Theory.

But the application of game ideas in the traffic signal timing is still in the initial stage. Alvarez et al. (2008) presents an approach to the urban traffic problem based on game theory and a Markov chain model which was applied to simple isolated intersections. Clempner and Poznyak (2015) presents a paradigm for modeling the multi-traffic signal-control synchronization problem using game theory based on the extra proximal method. It is proven that the Nash equilibrium can find an optimal signal timing strategy for a signal controller. Castillo (2015) deals with the solution of the multi-traffic signal control problem for continuos-time Markov games under the expected average cost criterion. Abdelghaffar et al. (2016, 2017) modeled a signalized intersection considering four phases and applied the Nash bargaining solution to obtain the optimal strategy. Li et al. (2012) adopted the idea and the selection mechanism of evolutionary game theory to examine an new signal light control mechanism.

The above studies about traffic signal control mainly focus on the applications of game theory in a single intersection or local situations but are not applicable for the whole traffic arterial. However, with the increasing complexity of urban transportation system, a functional and systematic coordination is required to improve the efficiency of a traffic network. Bazzan (2005) made use of techniques of evolutionary game theory: in which intersections in an arterial are modeled as individually-motivated agents and the traffic manager deals only with tactical ones. Srivastava (2016); Han (2015) presented a model which is based on Bi-level Stackelberg Game where the upper layer is "traffic signals" and the lower layer is "stochastic user equilibrium" respectively. Bui et al. (2017) used 2 game models (which are Cournot Model and Stackelberg Model) to deal with difference scenarios of traffic flow. Valencia et al. (2015) applied a bargaining-game-based coordination mechanism in congestion management of urban networks.

The chicken game is an interesting social dilemma with important practical applications. When two people play this game, each has two choices: cooperation or defection. If both cooperate, they both receive a certain reward. If both defect, they are both severely punished. The dilemma arises from the fact that if one of them cooperates but the other does not, then the cooperator receives a sucker's payoff while the defector gets a high reward. In view of the above-mentioned particularity, the chicken game is commonly used to explain many practical social and financial problems. A few researchers applied chicken game theoretic approach in the traffic signal timing. Ma and Liu (2011) used chicken game to set traffic light interval for single intersection. Under the hypothesis of economic person, the rationality of green signal ratio of traffic light intervals was investigated using the basic game theory. Elhenawy (2015) proposed a chicken game based algorithm for controlling autonomous vehicle movements equipped with cooperative adaptive cruise control systems at uncontrolled intersections. In this paper, traffic signal timing decision model based on chicken game was proposed for two adjacent intersections. Each intersection was defined as a game player and the queue length of the whole intersection was regarded as payoff function. Nash equilibrium of mixed strategies was obtained based on the chicken game model which belongs to a non-cooperative game, so the state of signal light in next game-cycle can be on-line adjusted. The digital characteristics and effectiveness of the proposed method was analyzed.

2 The Theoretical Framework of Chicken Game

For the sake of simplicity, and with no loss of generality, the double static game of chicken with complete information will be considered here. Where, the player *X* and *Y* both have 2 pure strategies which are 1 and 2, and the payoff matrix is given in Table 1:

Table 1. The payoff matrix of the chicken game.

X	*Y*	
	1	2
1	x_{11}, y_{11}	x_{12}, y_{12}
2	x_{21}, y_{21}	x_{22}, y_{22}

Notes: Where x_{ij}, y_{ij} are the payoffs of player X and player Y about the pure strategy combination (*i, j*) which satisfy the following constraints: $x_{21} > x_{11}$, $x_{12} > x_{22}$, $y_{12} > y_{11}$, $y_{21} > y_{22}$.

This game has three Nash equilibria which are listed as follows:

(1) pure strategy: (1,2)

(2) pure strategy: (2,1)

(3) mixed strategies: $((p^*, 1-p^*), (q^*, 1-q^*))$, where $p^* = (y_{22} - y_{21})/(y_{11} + y_{22} - y_{12} - y_{21})$, $q^* = (x_{22} - x_{12})/(x_{11} + x_{22} - x_{12} - x_{21})$, which means that the player X chooses the pure strategy 1 and 2 with the probability of p^* and $1 - p^*$ respectively,

and the player Y chooses the pure strategy 1 and 2 with the probability of q^* and $1 - q^*$ respectively.

The game of chicken allows multiple equilibria, so the expected game result can not be guaranteed. Moreover, the interests of the 2 players in the chick game are opposite under the pure strategic equilibrium, that is to say one side gains, then the other loses. Therefore, the chicken game describes a game in which the brave one is the winner fighting in the narrow alley. It is suitable for studying experimental paradigms of conflict and competition among individuals.

3 The Mutual Relevance of Traffic Flow Between Intersections

The continuity of the traffic flow on the road network depends largely on the coordination of signal timing in multiple intersections. During the vehicles travel from the stop line of the upstream intersection to one of the downstream intersection, the traffic flow will be discrete due to the difference of the vehicle's driving speed. Once the traffic flow parameters such as traffic volume, speed are changed caused by traffic signal timing or traffic congestion, the short-term changing characteristics of in traffic flow parameters can be maintained to the downstream intersection.

In Denney Jr. (1989), Traffic expert D. I. Robertson thinks that the relation between vehicle arrival rate for a certain downstream section and vehicle passing rate for an upstream stop line section meet the following mathematical formula:

$$q_d(i+t) = Fq_o(i) + (1-F)q_d(i+t-1) \tag{1}$$

Where i is the discrete observation time interval in the origin of the route after the start of the green light; is number of vehicles passing through the end of the route during the $i + t$ interval *(veh); F* is the dispersion coefficient, and $F = 1/(1 + \alpha t)$; t is the correction for average travel time, and $t = \beta T$ (s); T is the average travel time (s); α, β is the parameters to be calibrated, which are 0.35 and 0.8 respectively recommended by Robertson.

According to the traffic signal at the intersection B when the traffic flow from the upstream intersection A arrives at B and the traffic flow queuing at the downstream intersection, the traffic flow queues between the two intersections are divided into the following two types:

(1) The queue formed at the end of the first green light signal at the upstream intersection. At the end of the traffic signal of A intersection, the last vehicles passing through intersection A which can't directly pass through the intersection B due to meeting traffic red light signal or waiting queue form the first traffic flow queue.
(2) The queue formed at the beginning of second green signal at the upstream intersection. After the next green signal at intersection A, the vehicles passing through intersection A which meet red signal at intersection B or not completely dissipated queue at stop line form the second traffic flow queue

4 The Establishment and Solution of Traffic Signal Timing Decision Game Model for Adjacent Intersections

When the distance between two adjacent intersections is not enormous, traffic signal timing decision of one intersection has a great impact on the others.

There are two levels of game in the signal timing of the adjacent intersections: one is the chicken game of different phase flow between intersection *A* and intersection *B*, the second is the game between two intersections.

4.1 Game Between Internal Phases of the Intersection

The queue length of each phase i in the intersection is continuous in a sampling period, and satisfies:

$$w_i(k+1) = w_i(k) + c \cdot d_i(k+1) - v_i(k+1) \tag{2}$$

Where, k is the sampling period number of the intersection; c is the signal sampling period of the intersection (s); $d_i(k + 1)$ is vehicle arrival rate of each entrance of the intersection during the period $[kc, (k + 1)c]$ (veh/s); $g_i(k + 1)$ is the length of green time allocated to phase i in the $k + 1$ period (s); L_i is the saturation flow rate for phase i (veh/h); $v_i(k + 1)$ is the vehicle dissipation rate of the intersection during the period $[kc, (k + 1)c]$ (veh/s),which is relating to effective green time of the corresponding phase, reflects the average dissipation rate of the vehicle within the sampling time interval, and can be expressed as $[kc, (k + 1)c]$ (veh/s).

From what was said above, considering the non negative, we have:

$$w_i(k+1) = \max\{0, w_i(k) + c \cdot d_i(k+1) - L_i \cdot g_i(k+1)\} \tag{3}$$

Where $g_{\min} \leq g_k \leq g_{\max}$, and $\sum_{\mathrm{i}} g_i(k) \leq \mathrm{c} - z$, g_{min} and g_{max} are minimum and maximum green time respectively, z is the loss time.

Signal timing at the intersection with two phases is taken as the initial point of the study. In a intersection, there are two conflicting traffic flows, where both sides want to move forward and let the other back down to allow more vehicles to pass through. But only one phase can be in the green state at one time, the green phase of forward side obtains certain benefits, and the red phase of back side gets loss of some income. If both sides are forward, traffic accidents will cause great loss. If both sides are back, the traffic efficiency is 0 and a certain loss is produced. Chicken game describes how to make one's own advantages, strive to achieve maximum benefits, and ensure the minimum loss in confrontation conflict of two strong men. Thus the game of traffic flow in different directions can be regarded as a chicken game, in which only the game between vehicles can be considered.

Chicken game model between internal phases of the intersection is as follows:

(1) player:{phase 1, phase 2}. Each phase is expected to get a longer green time.
(2) strategy set: {Green light, red light}. The traffic signal state at the game point constitutes the strategy set of the players.

(3) Payoff: The opposite number of the queue length of the phase at the end of the game is defined as the payoff of each player.

Assuming that the east-west phase is player 1, the north-south phase is player 2. The initial state is that east-west phase is on green light, and north-south phase is on red light. The players play the game in the game point (i.e. at the beginning of the new game cycle), and the aim of which is to win the maximum payoff, that means that the total queue length of two phases reaches to a minimum at the end of the current game cycle. The game process is as follows: when player 1 takes the green light strategy and player 2 takes red light strategies, the payoffs of both sides are a and b respectively; when player 1 takes the red light strategy and player 2 takes green light strategy, the payoffs of both sides are c and d respectively; When the two sides both take the green strategy, the intersection will fall into chaos, and even cause traffic accident; When both sides take the red light strategy, the intersection will lose the capacity. Therefore, the last two kinds of situations should be avoided, the payoffs of both sides in game matrix are 0. Obviously, the game of phases belongs to static and complete information game.

The values of a, b, c, d above are determined by the vehicle queue length. Assuming that the game cycle is 30 s, according to the formula (3), for the k-th game points, we have:

$$a: \; w_1(k+1) = \max\{0, w_1(k) + 30 * d_1(k+1) - L_1 * 30\}$$

$$b: \; w_2(k+1) = \max\{0, w_2(k) + 30 * d_2(k+1)\}$$

$$c: \; w_1(k+1) = \max\{0, w_1(k) + 30 * d_1(k+1)\}$$

$$d: \; w_2(k+1) = \max\{0, w_2(k) + 30 * d_2(k+1) - L_2 * 30\}$$

Then the game payoff matrix of two phases of intersection is established as follows:

The game is a multiple Nash equilibrium game, where there are two pure Nash equilibrium strategies, which are (red, green) and (green, red) respectively. Since preferences and interest of both sides are completely inconsistent for the two Nash equilibriums above, the two Nash equilibriums are not stable in the non-cooperative game framework, which can not be as solutions of chicken game model. So we should find additional solutions with the stability, i.e. mixed strategy Nash equilibrium (Table 2).

Table 2. Payoff matrix of two phases of the intersection.

Phase 1	Phase 2	
	Green light	Red light
Green light	(0, 0)	(a, b)
Red light	(c, d)	(0, 0)

Let p_1 p_2 denote the probability of the random selection of the green strategy, then the mixed Nash equilibrium strategy is $((p_1, 1 - p_1), (p_2, 1 - p_2))$. According to the Nash theorem, we can deduced that $p_1 = d/(b + d)$, $p_2 = a/(a + c)$. The player select green policy to ensure the other's expected payoff of the red light strategy is equal to one of the green light strategy, so that the other party has to comity.

If a game cycle is 30 s, then the game runs every 30 s, and determine the status of each phase signal in the next 30 s (i.e. east-west phase keeps green light, north-south phase keeps red light or east-west phase jumps on to red light, north-south phase jumps on to green light). The maximum green time length of a phase is assumed to be 90 s, i.e. the continuous green light length shall not exceed 3 game periods.

4.2 Traffic Signal Timing Decision Model of Adjacent Intersections with Chicken Game

Due to the larger flow of main road, every intersection hopes to ensure smooth passage for the main road to make the whole queue length minimum. The intersection A expects B turns on the east-west direction light for the rapid evacuation of traffic flow when the east-west direction is in the green phase. So is for the intersection B. Therefore, for the intersection A, when the east-west direction is in the green phase, the best strategy for A is to make the payoff of the choice of green phase in east-west direction for B equal to one in the north-south for B.

Chicken game model for adjacent intersections is as follows:

(1) player:{intersection A, intersection B}

(2) strategy set: {Green light in east-west direction, red light in north-south direction, red light in east-west direction, green light in north-south direction}. The traffic signal state At the game point constitutes the strategy set of the players, and different combinations of traffic signals form different situations.

(3) Payoff: The opposite number of the queue length of the intersection at the end of the game is defined as the payoff of each player. The game results should give priority to ensuring main road traffic efficiency.

According to the formula (3), for the *k-th* game points, we have:

$$a_1 : \ w_{A1}(k+1) = \max\{0, w_{A1}(k) + 30 * d_{A1}(k+1) - L_{A1} * 30\}$$

$$b_1 : \ w_{A2}(k+1) = \max\{0, w_{A2}(k) + 30 * d_{A2}(k+1)\}$$

$$c_1 : \ w_{A1}(k+1) = \max\{0, w_{A1}(k) + 30 * d_{A1}(k+1)\}$$

$$d_1 : \ w_{A2}(k+1) = \max\{0, w_{A2}(k) + 30 * d_{A2}(k+1) - L_{A2} * 30\}$$

$$a_2 : \ w_{B1}(k+1) = \max\{0, w_{B1}(k) + 30 * d_{B1}(k+1) - L_{B1} * 30\}$$

$$b_2 : \ w_{B2}(k+1) = \max\{0, w_{B2}(k) + 30 * d_{B2}(k+1)\}$$

$$c_2 : \ w_{B1}(k+1) = \max\{0, w_{B1}(k) + 30 * d_{B1}(k+1)\}$$

$$d_2 : \ w_{B2}(k+1) = \max\{0, w_{B2}(k) + 30 * d_{B2}(k+1) - L_{B2} * 30\}$$

Then the game payoff matrix is established as follows:

Table 3. Payoff matrix of the adjacent intersections.

Intersection *A*	Intersection *B*	
	Green light in east-west direction, red light in north-south direction	Red light in east-west direction, green light in north-south direction
Green light in east-west direction, red light in north-south direction	$(a_1 + b_1, a_2 + b_2)$	$(a_1 + b_1, c_2 + d_2)$
Red light in east-west direction, green light in north-south direction	$(c_1 + d_1, a_2 + b_2)$	$(c_1 + d_1, c_2 + d_2)$

5 Simulation

5.1 Analysis of Digital Characteristics of Vehicle Queue Length of the Method

MATLAB is applied for the simulation of the signal timing decision of two adjacent intersections, where the main road is in the east-west direction, the branch is in the north-south direction. The settings of parameter are shown in Table 4.

Table 4. The parameter settings of timing simulation intersection with four phase.

Cycle	Loss time	Saturation flow of main road	Saturation flow of branch road	Vehicle arrival rate of main road	Vehicle arrival rate of branch road
30 s	2 s	0.5 *veh/s*	0.3 *veh/s*	$\lambda = 13$ *veh/c*	$\lambda = 8$ *veh/c*

Where the initial phase queue length is 0; The 200 step simulations are run with the game cycle C = 30 s as a unit. For the fixed time, the signal cycle of intersection A and B are set to 60 s; the loss time of a signal cycle is 4 s; Phase green time of main and branch road are 32 s and 24 s respectively.

Table 5 shows the maximum, mean and variance of vehicle queue length for the two adjacent intersections in the case of chicken game and fixed timing. For the intersection *A*, it can be seen that relative to the fixed time, the average vehicle queue length of the chicken game decreases, remaining at around 5 .When queue length of a phase is larger, it can be rapidly reduced by the adjusting the number of game period; From the variance, vehicle queue length fluctuation of each phase decreases slightly after the game; The maximum queue length of the game method is reduced relative to the fixed time. The intersection of *B* also has similar conclusions.

Table 5. Digital characteristics of vehicle queue length under different timing methods.

	Method	Intersection			
		Intersection *A*		Intersection *B*	
		Phase 1	Phase 2	Phase 1	Phase 2
Mean	Fixed timing	11.51	6.63	10.57	11.03
	Chicken game	4.27	6.61	4.38	5.20
Variance	Fixed timing	37.18	19.27	49.84	44.62
	Chicken game	23.71	35.06	24.29	40.93
Maximum	Fixed timing	27.80	18.75	27.90	28.60
	Chicken game	22.86	16.89	20.57	28.45

5.2 Analysis of the Method's Effectiveness

In the traffic signal coordination scenario, the goal is to bring as many neighbors in an arterial as possible to use the same signal plan since these are designed to allow vehicles to flow in one of two opposite directions through the intersections, without stopping at red lights.

Be n the number of agents and $\boldsymbol{Agt}$ the set of traffic signal control agents. In the scenario used as example here, the network L is an arterial composed of n intersections (agt_1, agt_2, agt_3,agt_4, agt_5,agt_6, agt_7, agt_8, agt_9 and agt_{10} in Fig. 1), each being designed as an agent. The range of interaction among neighbors is $r = 1$. Payoff matrix of the adjacent intersections can be seen in Table 3.

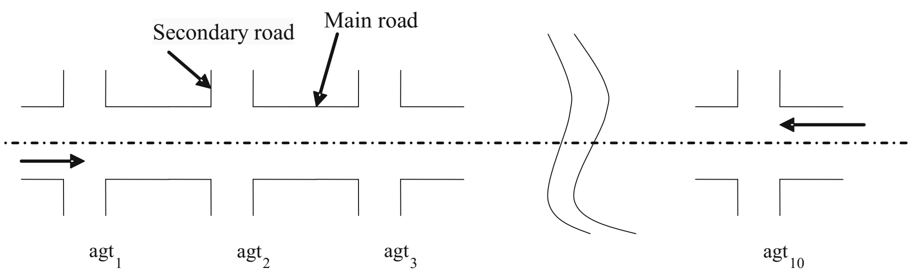

Fig. 1. Traffic arterial used in the simulations.

The condition of the traffic arterial is stable, but there are a few intermittent stoppings, and some intersections have lots of green light time losses. This phenomenon is caused by the use of the fixed traffic signal control of single intersection, the lack of coordination for traffic signals between intersections and the unreasonable traffic signal timing scheme at each intersection. The arterial represented in Fig. 1 was mapped to test the coordination of traffic signals. The current signal scheme of each intersection is shown in Table 6. According to the current signal timing scheme of each intersection, it can be seen that the releasing mode and signal cycle of each intersection are similar, so that it can be determined that there are a strong relevance and coordination conditions between intersections.

Table 6. Current signal scheme for intersections.

Intersection	Distance/m	Green time of each phase (east-west phase, south-north phase)	Signal cycle/s	Design speed/km/h	
				From west to east	From east to west
1	0	(80 s, 25 s)	105	–	60
2	591	(76 s, 24 s)	100	60	60
3	898	(78 s, 25 s)	103	60	60
4	486	(85 s, 25 s)	110	60	50
5	287	(77 s, 23 s)	100	50	50
6	222	(87 s, 26 s)	115	50	60
7	1053	(76 s, 24 s)	100	60	60
8	560	(80 s, 25 s)	105	60	55
9	335	(76 s, 24 s)	100	55	55
10	328	(90 s, 25 s)	115	55	–

Each agent at an intersection has local information acquired from detectors installed at the main lanes. With this information, an agent *i* is able to detect a change in the local traffic situation. The agent then compares the detectors' data and decide the more appropriate signal plan. Since the main lanes play the determining role in the kind of arterial considered here, two assumptions are made: by selecting the appropriate signal plan, the local traffic condition in the intersection *i* improves, and by interacting with neighbors, the traffic condition in the neighborhood also becomes better. By giving priority to the more congested of them, the queue length of vehicles is likely to decrease.

According to the arrival of the traffic flow and specified design speed, the signal cycle is unified to 110 s. The green time of each phase for intersections after optimization is shown in Table 7. The adaptive traffic signal coordinated timing decision

Table 7. Signal scheme for intersections after optimization.

Intersection	Distance/m	Green time of each phase (east-west phase, south-north phase)	Signal cycle/s
1	0	(84 s, 26 s)	110
2	591	(84 s, 26 s)	110
3	898	(84 s, 26 s)	110
4	486	(84 s, 26 s)	110
5	287	(84 s, 26 s)	110
6	222	(84 s, 26 s)	110
7	1053	(84 s, 26 s)	110
8	560	(84 s, 26 s)	110
9	335	(84 s, 26 s)	110
10	328	(84 s, 26 s)	110

Table 8. Comparison of effect indexes of the traffic arterial before and after optimization (from the west to the east).

The arterial direction	Section	Centralized traffic signal timing decision method		The game-based signal timing decision method	
		Travel time/s	Stopping number	Travel time/s	Stopping number
From the west to the east	1 → 2	54	1	37	0
	2 → 3	80	0	58	0
	3 → 4	58	0	57	1
	4 → 5	26	1	25	0
	5 → 6	48	0	27	0
	6 → 7	73	1	60	0
	7 → 8	64	0	39	0
	8 → 9	58	0	33	0
	9 → 10	103	1	73	1
Sum		564	4	419	2

improved the traffic efficiency of the traffic arterial, mainly illustrated by the two indexes such as average vehicle travel time and topping number. The comparison of travel time and topping number before and after optimization is shown in Tables 8 and 9. The results show that after the implementation of game coordination strategy, the west-east total travel time changes from 564 s to 419 s, reduced by 25.7%, and the total stopping number changes from 4 to 2. The east-west total travel time changes from 583 s to 410 s, decreased by 29.6%, and the total stopping number changes from 5 to 2.

Table 9. Comparison of effect indexes of the traffic arterial before and after optimization (from the east to the west).

The arterial direction	Section	Centralized traffic signal timing decision method		The game-based signal timing decision method	
		Travel time/s	Stopping number	Travel time/s	Stopping number
From the east to the west	10 → 9	43	1	21	0
	9 → 8	23	0	22	0
	8 → 7	55	1	34	0
	7 → 6	121	1	103	1
	6 → 5	28	0	19	0
	5 → 4	39	1	20	0
	4 → 3	87	0	38	0
	3 → 2	84	1	99	1
	2 → 1	103	0	54	0
Sum		583	5	410	2

6 Conclusion

Traffic signal timing decision model based on chicken game was proposed for two adjacent intersections. Each intersection was defined as a game player and the queue length of the whole intersection was regarded as payoff function. Nash equilibrium of mixed strategies was obtained based on the chicken game model which belongs to non-cooperative game, so the state of signal light in next game-cycle can be on-line adjusted. Relative to the other non-coordinated method like fixed timing control, the queue length of each phase can be obviously reduced. Simulation results showed that the game-based mechanism has proved more efficient when comparing the values of the total vehicle travel time and topping number at each section of the arterial. It will be demonstrated that the novel method offers the capability to provide distributed control as needed for scheduling multiple intersections.

In future work, it would be interesting to incorporate the coordination effects of driver behavior, transit signal priority and connected and automated vehicles in our framework. Moreover, the basic traffic arterial considered here will be expanded to include lager traffic networks and more extensive collaboration among intersections.

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