Power Consumption Based Multi Agent Intersection Management Method

Ferit Hacıoğlu[1], Mehmet Turan Söylemez[2]

[1]AVL Turkey Research and Engineering, 34920 Sultanbeyli, Istanbul, Turkey
ferit.hacioglu@avl.com
[2]Istanbul Technical University, Faculty of Electrical and Electronics Engineering, 34469 Maslak, Istanbul, Turkey
soylemezm@itu.edu.tr

Abstract

In this study a multi agent based intersection management algorithm is introduced by considering fully automated vehicles. Intersection management method is developed and simulated on a framework which is designed for this study. Vehicles entering the intersection communicates with each other and routes are simulated. A decision is made according to future positions to obtain a passing sequence without any collision. Vehicle velocity trajectories are manipulated to avoid collision at the intersection reducing Power consumption due to acceleration and deceleration.

1. Introduction

Developments in the vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) technologies encourage studies on self-organized traffic management systems instead of traditional traffic light solutions. Rapidly increasing communication capability between vehicles and field units allows us to regulate traffic flow at the intersections by considering position and velocities of the vehicles which enter the intersection. Generally, intersections are controlled by the traffic lights. However, predetermined traffic light control mechanisms may cause unnecessary stops or decelerations. There have been many works regarding intersection management with traffic light scheduling.

An optimal traffic light control for single intersection is given in [1] with model derivation for the evolution of the queue lengths. A fuzzy logic based traffic light control method is proposed for an isolated intersection including traffic abnormality such as road blocks and accidents [2]. Lyapunov function-based analysis and maximal weight matching algorithm is given for an isolated intersection in [3].

The recent approaches are multi agent based intersection management methods. There are several works on multi agent intersection management. Reservation based intersection management systems are introduced by K. Dresner and P. Stone [4]. Vehicles approaching intersection send a reservation to a field unit or each other, and request permission to pass the intersection. Reservation request generally includes estimated position and velocity of the vehicle. The reservation is evaluated depending on the intersection status and the other vehicles requests. Some reservation policies are explained in [4, 5]. A reservation based approach for the situations when autonomous vehicles meet human drivers is explained in [6]. A platoon based approach, which allows only the leader agent to get a reservation for whole platoon, is proposed by Q. Jin et al. [7].

Main aim of the intersection management is to prevent any possible collisions at the intersection. In many studies, intersection is modelled as grids so that the possible conflict of the vehicle's future positions can be detected [8]. Similar approach for the collision detection is explained for roundabouts in [9]. In order to predict the collision at the intersection, routes of the vehicles can be simulated. Considering the capabilities of the control units integrated into vehicles, route simulation can be easily done by each vehicle itself. After the collision detection, vehicles are conditioned to prevent the possible collision.

If there is a conflict in reservations, the reservation with the higher priority is approved and the other reservations are rejected. Priority is mostly decided by First Come – First Serve (FCFS) principle. FCFS principle is first introduced by K. Dresner and P. Stone [5]. In FCFS, the vehicle, which is estimated to enter the collision grid first, takes the priority to pass the area first. Priority levels can also be set according to trip and route information as discussed in [8]. Priority override due to the existence of an emergency vehicle is given in [10].

Trajectory of the vehicle with lower priority is adjusted to allow the vehicle with the higher priority to pass the collision grid first. Scheduling between vehicles appears in the delays on the estimated arrival times to the intersection. Vehicle velocity trajectories are adjusted to fulfill the delay times. A motion planning algorithm depending on estimated arrival time to the intersection is explained in [11]. Velocity adjustment including acceleration and deceleration, based on a calculated average speed is explained for connected vehicles in [12].

In this study we focused on the scheduling decision making. In [13], a time delay based method is proposed and is stated that the FCFS in not efficient in term of total delay. It is shown that some passing sequence of the vehicles through the collision grid, could result in less total time delay compared to FCFS.

We examined this decision problem in terms of power consumption. Since the delay time are fulfilled with deceleration and acceleration on the velocity trajectories, power consumption loss is inevitable. Each passing sequence will cost differently in terms of power loss. The sequence with the minimum power loss is selected. Besides, we combined the total delay time and power loss in one cost function to consider the time delay as well. A MATLAB based intersection framework is designed for the simulations.

This paper is organized as follows. The intersection model is explained in the next section. In the section 3, delay time realization is presented. In the section 4, proposed method is explained. The section 5 is devoted to simulation results and in the final section the conclusion and future work are discussed.

2. Intersection Model

Our intersection model consists of three main parts as discussed in [8]. This approach allows us to determine when the vehicles communicate and when they take action. A Similar communication area boundary to allow vehicle communication is given in [14].

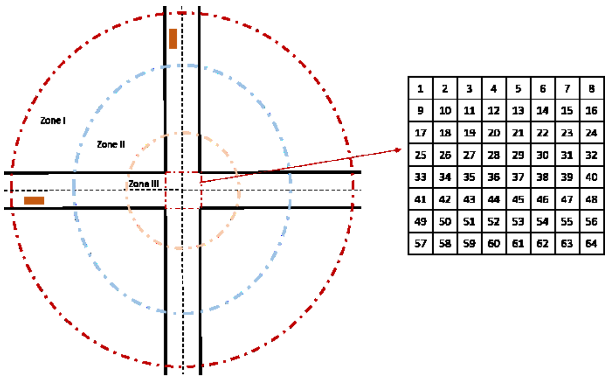

Fig. 1. Intersection model

Intersection area is divided into three main zones by circles as shown in the Fig. 1. The vehicles, inside the Zone I, are considered as to pass the intersection, while the vehicles outside Zone I are not concerned. As a vehicle is passing through the Zone I, it communicates with the other vehicles which are also inside the Zone I. Communicating vehicles share information of their estimated arrival time to the intersection and the estimated position in the intersection at that time. In Zone I, intersection management algorithm is run by all the vehicles. If there is a possible crash, safe velocity trajectories are created.

Velocity adjustment will be explained in the next section. Adjusting the velocities result in delay times for the vehicles arriving the intersection.

In the Zone II, vehicles, which are determined to be delayed, start to slow down depending on their delay time. In the Zone III, vehicles accelerate to their initial velocities. In Zone II and III, no communication between the vehicles takes place.

Vehicles are conditioned in Zone I so that there will be no crash. Passing decision is recalculated every time a new vehicle enters Zone I. Delay times are assigned to the vehicles based on the passing decision. Once a vehicle passes into Zone II, its delay is set permanently. This means the reservation of the vehicle is approved. We call this approval as globally set delay time. All new delay calculations are conducted over the globally set time delays. Globally set reservation information is considered to be shared through the vehicles. Vehicles entering Zone II sends this information to the vehicles in Zone I. However, if there is a long distance between two vehicles, which contains the length of Zone I, there is a possibility that the information is not passed through the vehicles. In this case, if the vehicle at the back, travels too fast, may reach the intersection at the same time with another vehicle. This situation can be overcome by deployment of a field unit to increase safety; however, this problem is not in the scope of this study.

2.1. Crash Detection

Main intersection area is divided into 8x8 grids as shown in the Fig. 1. These grids are used to detect crashing vehicles. Once a vehicle enters Zone I, all the vehicles traveling in Zone I communicate and each of them simulates their travel through intersection. Simulated trajectories are compared and the possible crash is detected as shown in Fig. 2. Paths of the vehicle 1 and vehicle 2 intersects at the square numbered by 50. If both vehicles pass the square 50 at the same time according to the estimated paths, a crash will be detected.

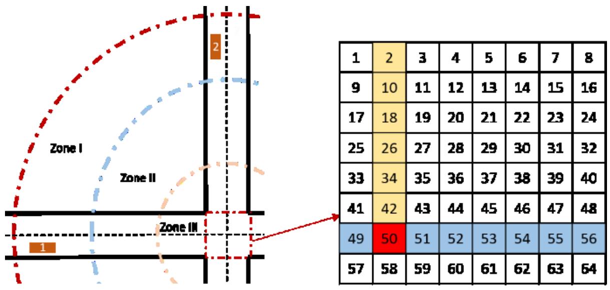

Fig. 2. Crash detection for two vehicles

3. Velocity and Acceleration Profile Generation

Estimated crashes in the intersection based on the estimated positions of the vehicles are prevented by adding delays on the travel times. Time delay calculation will be explained in the next section.

In order to fulfill the time delays, vehicles must decelerate and accelerate. The velocity profile represented in Fig. 3, is constructed based on the delay time. In this work, all vehicles are assumed to travel with constant velocity once they enter the Zone I. Time delay is split into two parts for both deceleration and acceleration as discussed in [8]. Deceleration starts at T_1 and lasts until T_2. The difference between T_2 and T_1 is the time spent in the Zone II. Similarly, travel time in Zone II is the difference between T_3 and T_2, which is the acceleration interval.

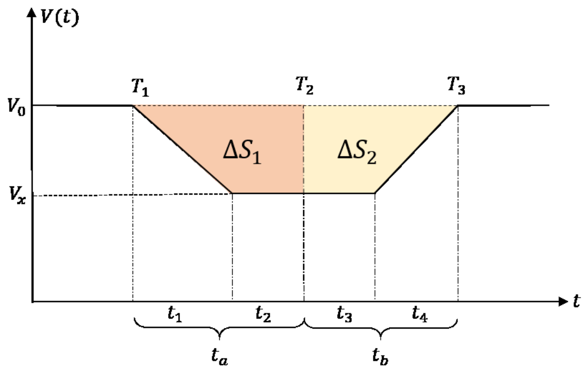

Fig. 3. Velocity profile for delay time realization

Acceleration and deceleration are calculated by the following equations:

$$t_a = t_1 + t_2 \tag{1}$$

$$t_1 = t_a \cdot \gamma \tag{2}$$

$$t_a = \frac{S_1}{V_0} + T_d \cdot \alpha \tag{3}$$

$$\Delta S_1 = V_0 \cdot t_a - S_1 \tag{4}$$

$$V_x = V_0 - \frac{2\Delta S_1}{t_1 + t_a} \tag{5}$$

$$a_{decel} = \frac{V_x - V_1}{t_1} \tag{6}$$

Here, S_1 is the deceleration distance which is the difference between Zone II radius and Zone III radius. T_d denotes the total time delay, while α is the ratio for splitting the time delay. V_0 is the initial vehicle velocity. γ denotes the ratio between deceleration and constant speed durations. Here, α and γ are chosen as 0.5 for simplicity. These ratios can be adjusted depending on maximum acceleration and deceleration limits of the vehicles and also deceleration and acceleration distances [8, 10].

$$t_b = t_3 + t_4 \tag{7}$$

$$t_b = \frac{S_2}{V_0} + T_d \cdot (1 - \alpha) \tag{8}$$

$$\Delta S_2 = V_0 \cdot t_b - S_2 \tag{9}$$

$$t_4 = 2\left(t_b - \frac{\Delta S_2}{V_0 - V_x}\right) \tag{10}$$

$$a_{accel} = \frac{V_0 - V_x}{t_4} \tag{11}$$

Here, S_2 is the acceleration distance which is the Zone III radius.

4. Intersection Management

In this section, we propose a multi agent reservation based intersection management method to reduce the power loss. Delaying arrivals of the vehicles to the intersection results in power loss due to the deceleration and the acceleration.

Method requires estimated time and position of the vehicles at the intersection once they enter intersection area. Vehicles communicate with each other and decide a passing sequence to avoid crash at the intersection by considering minimization of power and time loss. Delay time calculation is show in Fig. 4.

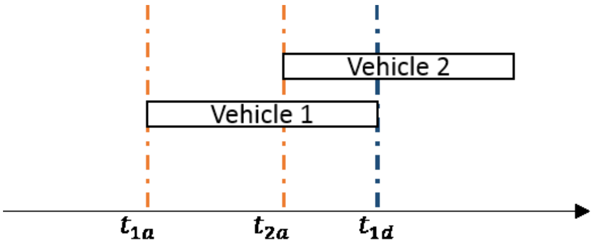

Fig. 4. Delay time

Arrival time to the crash area for vehicle 1 is t_{1a}, departure time is t_{1d} and the arrival time for the vehicle 2 is t_{2a}. If the vehicle 1 will pass the area first, then the delay time for the vehicle 2 is calculated as below:

$$t_{delay} = t_{1d} - t_{2a} \tag{12}$$

If there is a crash at a grid, passing sequence must be resolved to avoid crash. However, this intervention might possibly effect the vehicles which follow the delayed vehicles in the Zone I. For example in Fig. 5, if the vehicle 3 has the priority to pass first, vehicle 1 must delay its arrival to the intersection. In that case, a new crash situation might occur between vehicle 1 and vehicle 2. Thus, the vehicle 2 must be delayed as well.

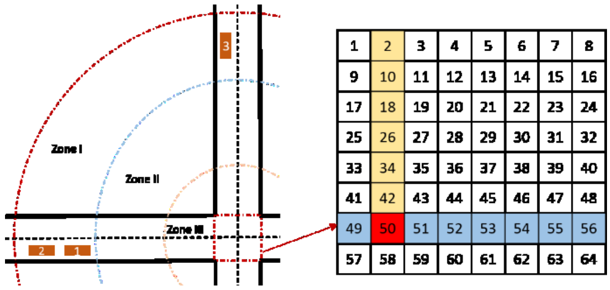

Fig. 5. Crash detection for three vehicles

Simplest approach to avoid crash is First Come First Serve method. In FCFS, the first vehicle arriving the crash grid has the priority. The inefficiency of this method is explained in [13]. Examining the permutation of the vehicles which will pass though crash grid will increase possibilities for improvement on efficiency. For the case introduced above, there are 3! = 6 passing sequences. However this number can be reduced by eliminating impossible sequences such as the cases vehicle 2 passes before vehicle 1 as shown below.

$$\left.\begin{matrix} 1 & - & 2 & - & 3 \\ 1 & - & 3 & - & 2 \\ 2 & - & 1 & - & 3 \\ 2 & - & 3 & - & 1 \\ 3 & - & 1 & - & 2 \\ 3 & - & 2 & - & 1 \end{matrix}\right\} \rightarrow \begin{matrix} 1 & - & 2 & - & 3 \\ 1 & - & 3 & - & 2 \\ 3 & - & 1 & - & 2 \end{matrix}$$

For each sequence, the vehicles have different delays to prevent any crash at the intersection. Minimum total delay time is aimed in [13].

Delay on the vehicles will cause loss in power consumption, since the vehicles will decelerate and accelerate to fulfill the delay time. Velocity, vehicle mass, air drag coefficient, rolling resistance might differ for different vehicles. Since the vehicles are not identical, same delay time will effect differently for each vehicle in terms of power consumption. In this work, minimum power loss is also taken in consideration to select passing sequence.

Power consumption for a velocity profile can be derived from traction force. Required traction force for a vehicle to follow given velocity profile can be calculated by the following equation.

$$\begin{aligned} F_{tra}(t) = ma(t) + &\frac{1}{2}\rho_{air} c_d A v^2(t) \\ &+ c_r m a_g v(t) \cos(\theta) \\ &+ m a_g \sin(\theta) \end{aligned} \tag{13}$$

Here, v denotes the vehicle velocity; ρ_{air} denotes the air density; c_d denotes the aerodynamic drag coefficient; A denotes the frontal area of the vehicle; c_r denotes the rolling friction; m denotes the vehicle mass; a_g denotes the gravitational acceleration and θ denotes the road slope. Required traction power can be calculated as follows.

$$P(t) = F_{tra}(t) \cdot v(t) \tag{14}$$

Since the vehicle parameters are known, each vehicle can calculate its required traction power depending on velocity and acceleration profiles. Power loss can be derived comparing requested powers for delayed and not delayed velocity profiles.

First, all possible passing sequences and corresponding delay time distribution is calculated. Then power loss is calculated based on the delay time values. A total power loss for each passing sequence is obtained. Sequence selection can be performed depending on minimum power loss.

In order to consider both power loss and time delay together, both losses can be combined as a one cost for sequence selection. Time and power loss can be represented as percentage since the nominal arrival time and power consumption is known.

$$J = \alpha \cdot T_{pctg} + (1-\alpha) \cdot E_{pctg} \quad ,\alpha \in [0,1] \qquad (15)$$

Here, T_{pctg} denotes the total time delay for a passing sequence; E_{pctg} represents the total power loss for a passing sequence. α denotes the ratio for the effects of time delay and power loss. α can be adjusted depending on the requirements of the intersection. It can be set as 1 or 0 to switch between two minimization requests.

5. Case Study

We developed an intersection simulation framework in MATLAB. Vehicles are created with their initial position, velocity, mass and path. Path following is accomplished by pure pursuit algorithm. Vehicle dynamic equation parameters are set as constant for each vehicle except mass. Effective frontal area is selected for a regular sedan type car, and rolling resistance is selected for asphalt road as given in [15]. Parameter values are in Table 1. Radius of Zone I, Zone II and Zone III are $200m$, $130m$ and $65m$ respectively. Maximum acceleration is set as $1.6m/s^2$ and minimum deceleration is $-1.6m/s^2$. Zone lengths are related to the maximum allowed speed and deceleration. In this paper, these values are selected as introduced in [8].

Different scenarios were run depending on velocity, path, and number of vehicles on the roads. A simulation scenario is shown in Fig. 6. All vehicles travel with constant velocity. Vehicle 1 and 2 turns the southern part of the intersection. Masses of the vehicle 3 and 4 are set higher than the other vehicles. Vehicles 5 to 10 constitutes a motorcade.

Table 1. Vehicle dynamic equation parameters

Parameters	Values
ρ_{air}: Air density	$1.24\ kg/m^3$
$c_d \cdot A$: Effective frontal area	$0.6m^2$
c_r: Rolling resistance	0.0012
a_g: Gravitational acceleration	$9.81\ m/s^2$
θ: Road gradient	$0\ rad$

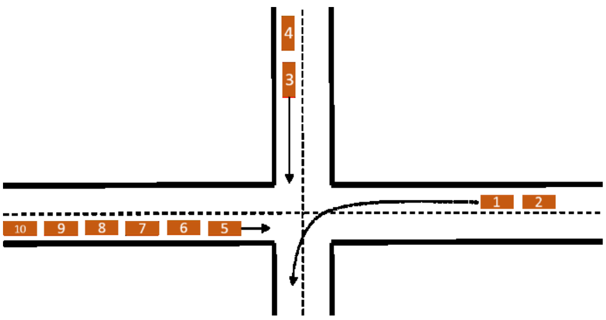

Fig. 6. Scenario 1 visualization

Table 2. Scenario 1 simulation results

	Config. 1	Config. 2	Config. 3
Vehicle 1	0 sec.	0 sec.	0 sec.
Vehicle 2	0 sec.	0 sec.	0 sec.
Vehicle 3	1.1 sec.	0 sec.	1.1 sec.
Vehicle 4	5.3 sec.	0 sec.	1 sec.
Vehicle 5	0 sec.	0 sec.	0 sec.
Vehicle 6	0.3 sec.	3.75 sec.	0.3 sec.
Vehicle 7	1.2 sec.	3.2 sec.	2.75 sec.
Vehicle 8	0.65 sec.	2.65 sec.	2.2 sec.
Vehicle 9	0.1 sec.	2.1 sec.	1.65 sec.
Vehicle 10	1.05 sec.	1.55 sec.	1.1 sec.
Time Loss	9.7 sec.	13.25 sec.	10.1 sec.
Power Loss	-4.70 %	-3.06 %	-4.04 %

Simulation results are seen in Table 2. Total delay time based sequence selection is named as configuration 1. Power loss based sequence selection results are in column configuration 2. Combination of the power loss and time loss based selection results are configuration 3.

Zero delay times on vehicle 3 and 4 are expected in power loss based configuration, since the weights of the vehicle 3 and 4 are higher than the others and this leads more power loss during acceleration. Similarly, vehicle 5 to 10 have less delay in configuration 1 compared to configuration 2, since delaying the head of a motorcade results in consecutive delays on the following vehicles. In configuration 3, it is seen that total delay is increased; however, power loss is decreased compared to configuration 1. Similarly, power loss is increased while reducing total delay compared to configuration 2.

Different scenario results for configuration 1 is seen in Table 3. Scenario 1 is the same simulation explained above. In scenario 2, 11 vehicles are simulated similar to scenario 10. In scenario 3, 4, 5 and 6, 15 vehicles are simulated on the all paths of the intersection with varying weights, and velocities. Simulation results for configuration 2 and 3 are seen in Table 4 and 5 respectively.

Simulation results show that the total time delay minimization based sequence selection results in less delay than total power loss based sequence selection. Similarly, total power loss based sequences reduces power loss compared to time based sequences.

Table 3. Simulation results for configuration 1

Scenarios	Total Time Loss	Total Power Loss
Scenario 1	9.7 sec.	-4.7 %
Scenario 2	16.9 sec.	-6.25 %
Scenario 3	23.6 sec.	-5.91 %
Scenario 4	21.6 sec.	-5.53 %
Scenario 5	31.4 sec.	-5.97 %
Scenario 6	32.4 sec.	-8.35 %

Table 4. Simulation results for configuration 2

Scenarios	Total Time Loss	Total Power Loss
Scenario 1	13.25 sec.	-3.06 %
Scenario 2	17.5 sec.	-3.23 %
Scenario 3	27.95 sec.	-4.54 %
Scenario 4	32.8 sec.	-3.84 %
Scenario 5	54.95 sec.	-3.73 %
Scenario 6	41.05 sec.	-5.75 %

Table 5. Simulation results for configuration 3

Scenarios	Total Time Loss	Total Power Loss
Scenario 1	10.1 sec.	-4.04 %
Scenario 2	13.35 sec.	-4.25 %
Scenario 3	32.55 sec.	-4.13 %
Scenario 4	31.55 sec.	-5.27 %
Scenario 5	40.8 sec.	-3.68 %
Scenario 6	33.7 sec.	-5.2 %

It is observed that the configuration 3 improves the configuration 1 in terms of power loss and improves the configuration 2 in terms of total delay as expected. However, total time delay improvement is seen in scenario 2 for configuration 3 compared to the configuration 1. Similarly, total power loss reduction is observed in scenario 3, 5 and 6 for configuration 3 compared to the configuration 2. This can also be expected since the algorithm does not guarantee the global minimum. Since the number of the vehicles which will pass the intersection cannot be known, all minimum time delay and power loss based selections are conducted between communicating vehicles in Zone I.

6. Conclusions and Future Work

In this article, a multi agent intersection management method is introduced. Power loss reduction is aimed while avoiding crash at the intersection by the proposed method. Power loss is derived based upon vehicle longitudinal dynamics.

An intersection simulation framework is developed in MATLAB. Intersection is divided into three part to specify communication, deceleration and acceleration areas. Crash detection is performed by simulating vehicle's paths. Crash detection and vehicle conditioning to avoid crash is conducted in the communication area. Delay times are assigned to the vehicles to avoid crash. Delay times are realized during deceleration and acceleration.

The proposed method provides an improvement for delay time assignment considering the power loss which will occur during the deceleration and the acceleration. Delays are assigned between the communicating vehicles to minimize the power loss. The results are compared with a total delay reduction based method. Finally, combination of time loss reduction and power loss reduction is stated as a cost function.

The future work can be summarized as follows:

- Road gradient information can be provided to the vehicles, so that the predictive energy regeneration can be considered for power loss reduction method.
- Time and power percentage loss ratio for the combined cost can be enhanced for discretizing the ratio for each vehicle as a vector. Power or time loss costs can differ for different vehicles.
- Velocity profile generation can be enhanced to cover inconstant velocity cases.
- Multi intersection structure can be established to have information of the vehicles which approach to the intersections. This may increase convergence to the global minimum.

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