Construction and Performance Evaluation of the Platoon-Formation Algorithm Considering the Destination of Each Vehicle

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Abstract

These days, the number of vehicles is explosively increasing and vehicles have the important roles in communities from the viewpoint of transportation. In this situation, the increase of traffic jam becomes one of serious social problems. It is said that the loss by the traffic jam in Japan is more than 7 billions yen.

The next generation vehicles is being proposed and under developing. In the near future, "driving automatically" becomes common technologies in usual life.

To solve such problems as traffic jam and the first step of driving automatically, "Platoon" is proposed. But the formating method of Platoon has several problems. So we proposed "Platoon-Formation Algorithm(PFA)". In PFA, each platoon considers vehicles' destination when constructing and merging.

1 Introduction

It has passed more than 100 years since vehicular technology was born. Now, the techniques which people require of vehicles are not only "speed faster" but also "safety and comfort". Meet this demand, "Platoon" is proposed[1][2][3].

Platoon is defined as vehicles run with standing one behind another in a line and keeping very short vehicular gaps. Vehicles in a platoon are usually exchanging each other's information (i.e. destination, traveling speed, steering, acceleration and so on), using inter-vehicle communication system. Each vehicle constituting a platoon can control itself using these information to keep safety with shorter vehicular gap. In addition, drivers except a leading vehicle's don't have to control, because vehicles run automatically by following the leading vehicle.

In terms of these advantages, platoon makes higher road-capacity, and smaller drivers' controlling time. And the effect which decreases traveling time is expected. In this paper, such a platoon is called as "pure platoon".

But there aren't no problems in Platoon. For example, some vehicles in a platoon may intend to leave near the exit. Thess events occur with no relation to the position in a platoon. If the case of one vehicle leaving, one left operation is needed, two vehicles, two operations, three vehicles, three.... To perform these operations, it costs some space and some operation terms. Therefore, vehicles must slow down. It may be an another cause of reducing the performance. The more the number of vehicles increase, the worse the efficiency of the road. At last it may causes traffic jam near the exit.

In order to prevent from this situation, this thesis proposes "Platoon Formating Algorithm(PFA)". In this algorithm platoon considers the destination of vehicles to formate itself. This means each vehicle in a platoon is ordered by its destination. In this paper, destination means the exit position from the road(highway).

This algorithm includes construction and rearranging method. Construction is the way vehicles joining in and leaving from a platoon. Rearranging is the way to merge two platoons. In the case of "pure platoon", two platoons approach closely each other, the latter platoon merges with the former as they are. But in PFA, each platoon form a line with destination order, so if one pla-

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toon merges simply with another, the destination order will be broken. Rearranging is the method for such case to keep this order.

As a result of ordering, the vehicles which have same destination are gathered in a platoon. Platoon executes only one left operation near the exit (see Fig.1). So PFA prevents performance decreasing near the exit, and increases the efficiency of the whole road.

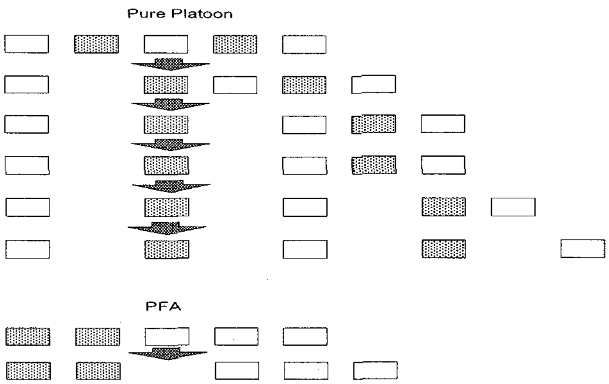

Figure 1: leaving from platoon

There are some proposals for inter-vehicle communication [4] [5] [6] [7] [8] [9] [10]. We used DPA(Dynamic Pn-code Assignment) as communication protocol and Passing Scheme as routing protocol[4].

2 Platoon Construction Algorithm

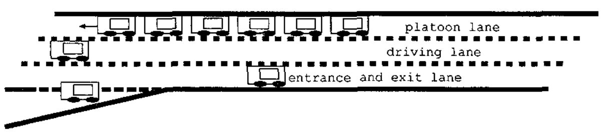

Figure 2: Highway in the simulations

We assumed the highway like Fig.2. The utilization describes below.

- right lane as platoon lane : platoons occupationally.
- center lane as driving lane : vehicles, rearranging platoon.
- left lane as entrance and exit lane : vehicles run, enter or exit.

We explains "Platoon Construction Algorithm(PCA)" which is to join in and leaving from the platoon. We considered four cases as follows in case of a vehicle tries to join a platoon.

- case 1 : Both any platoons and any vehicles trying to join a platoon don't exist closely.
  In Fig.3, Vehicle 1 changes the lane and makes a platoon alone.

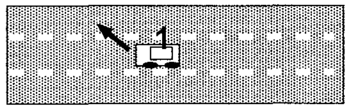

Figure 3: case 1

- case 2 : Any platoons don't exist but a vehicle trying to join a platoon exists closely.
  In Fig.4, dest.A is the closest destination. The destination of vehicle 2 is closer than that of vehicle 1. Vehicle 1 and 2 change the lane and make the platoon, of which the forward is vehicle 2 and the back is vehicle 1. Like this, the vehicle which has closer destination, the forwarder the vehicle is in the platoon.

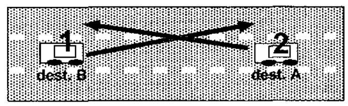

Figure 4: case 2

- case 3 : A platoon exists closely.
  If a platoon exists near the vehicle, the vehicle investigates the destinations of the vehicles in the platoon and compare them. The order of priority is described below. In Fig.5, dest.A is the closest destination and dest.C is the furthest.
  1. A vehicle could enter in front or back of the platoon.
     - The destination of the vehicle equals to that of the front or back vehicle of the platoon.
       In Fig.5-(a), since the destination of vehicle 3 is the same as that of vehicle 1, vehicle 3 joins to the platoon at the position front of 1.
     - The destination of the vehicle is closer than the front vehicle or further than the back one of the platoon.
       In fig.5-(b), the vehicle changes the lane and merge the front or back of the platoon. Since the destination of vehicle 3 is further than that of vehicle 2, vehicle 3 joins to the

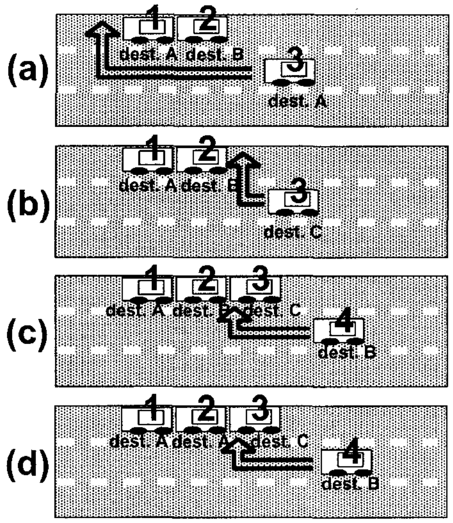

Figure 5: case 3

platoon at the position back of vehicle 2.

2. The destination of vehicle equals to that of the vehicle(s) in platoon except head and tail one.
   In Fig.5-(c), since the destination of vehicle 4 is the same as that of vehicle 2, vehicle 4 tries to split at the back of vehicle 2 in the platoon. Vehicle 4 joins to the platoon at the position back of vehicle 2.
3. The destination of vehicle is closer than that of tail one of platoon and further than that of head one.
   In Fig.5-(d), since the destination of vehicle 4 is further than that of vehicle 2 and closer than that of 3, vehicle 4 tries to join the back of vehicle 2 (the front of vehicle 3) in the platoon.

- case 4: Several platoons exist closely.
  The vehicle calculates the priority of each platoon as case 3, and chooses appropriately and joins in the platoon.

3 Platoon Rearrangement Algorithm

By using "Platoon Construction Algorithm", it is able to construct a platoon by the order of their respective destinations. In order to guarantee the order, each platoon is not allowed to merge with its adjacent platoons. This causes lack of road utilization by means of road capacity, since each platoon can not grow up.

To avoid this problem, we propose an algorithm named "Platoon Rearrangement Algorithm(PRA)". This algorithm defines a simply way to merge platoons and to keep vehicles' destination order in the platoon.

3.1 PRA architecture

Now, we will consider about Fig.6. There are two platoons and the distance between the platoons becomes closer. In this case, vehicle 3 and 4 will communicate

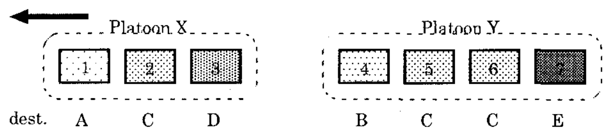

Figure 6: Platoon rearrangement case

each other by inter-vehicle communication. Since each vehicle in two platoons communicates with adjacent vehicles, the information from vehicle 3 can be transmitted to vehicle 1 by the sequentially passing. The information from vehicle 1 is also transmitted to vehicle 4. So vehicle 1 can communicate with vehicle 4 indirectly.

Each vehicle(vehicle 1 and 4) is a lead vehicle of each platoon and it knows the member of its platoon. We call the table of members as Platoon Table.

To merge two platoons, (in this case, we assume vehicle 4 begins merge operation) vehicle 4 sends Merge Request to vehicle 1. When vehicle 1 receives Merge Request, it checks the status of platoon X. Status means the operation of platoon X just managing, speed, vehicular gaps in front of the platoon, the positions of vehicles around the platoon and so on. If vehicle 1 founds no obstacle status, it sends Merge Ack. to vehicle 4 with Platoon Table of X.

After receiving the Merge Ack. with Platoon Table of X, vehicle 4 calculates the shortest merge operation order.

First, vehicle 4 calculates the time T_1 that Platoon X will merge to Platoon Y. This means the time that all of the X will leave from X and then merge to Y using side lane respectively. In some case, more than one vehicle can move at the same time. It is accomplished only when the move of the vehicles never break the order of Platoon Y(see fig.7). Each leave and join operation is same as Platoon Construction Algorithm.

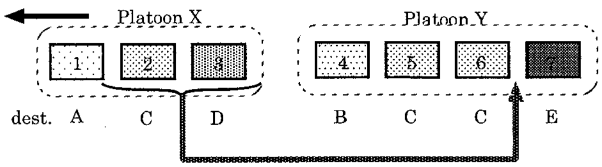

Figure 7: The case of several vehicles move.

Second, vehicle 4 calculates the time T_2 that Platoon Y will merge to Platoon X.

Vehicle 4 will adopt the shorter time of T_1 and T_2, and begin the transaction of rearrangement in the following sequence.

1. Vehicle 4 transmits the order of the rearrangement operation to vehicle 1.
2. After receiving the order, vehicle 1 sends ack. to vehicle 4.
3. Vehicle 4 waits the ack., and then begins the rearrangement operations.

Each part of the rearrangement operation is same as Platoon Construction Algorithm described in the previous section.

The rearrangement operation becomes the collections of the operations. In the case of Fig.6, the typically rearrangement operation is described below(see Fig.8).

(a) Platoon X will split to two parts, (vehicle 1) and (vehicle 2, vehicle 3).

(b) The group consists of vehicle 2 and 3 forms new Platoon X'. Platoon X' changes the lane.

(c) Platoon X' changes the speed slower to move towards the appropriate position of Platoon Y. Platoon Y opens the space at appropriate position to accept Platoon X'.

(d),(e) Platoon Y accepts Platoon X'. At this time, Platoon Y includes vehicle 2 and 3, and it still keeps the order of the destination of each vehicle.

(f) Platoon Y changes the speed faster to merge vehicle 1.

(g) Platoon Y merges vehicle 1.

After these operations, Platoon X and Platoon Y are merged without breaking the order of destination.

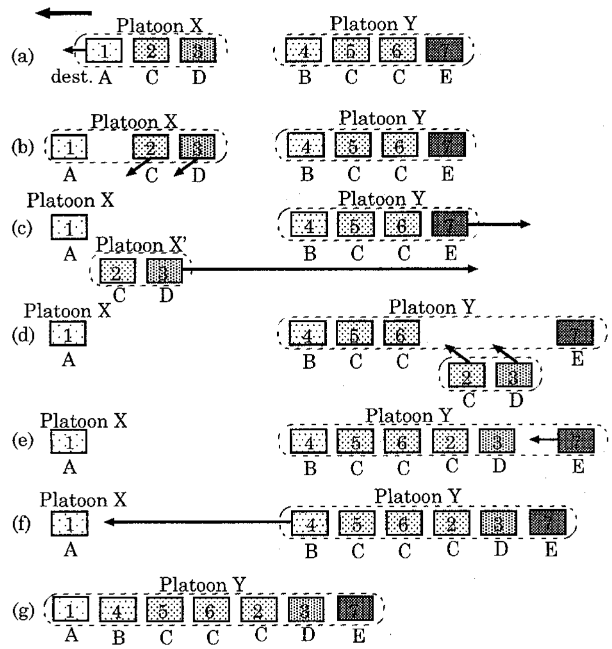

Figure 8: The example of merging operations.

4 Simulation Results

We evaluated the performance of PFA by computer simulations. Parameters is described below.

- road length : 50km
- number of lanes : 3
- normal speed at platoon lane : 100km/h
- normal speed at driving lane : 80km/h
- normal speed at entrance and exit lane : 60km/h
- simulation time duration : 2000 sec
- intervals between exit : 6km

Fig.9–Fig.11 shows the result of changing the number of vehicles from 1000 to 1700 on assumed highway. The percentage of vehicles consisting platoon is 100 %. Fig.9 shows average controling time. Fig.10 shows normalized average traveling time. From the results, average controlling time is hardly affected by the number of vehicles. By using pure platoon, average controlling time is reduced to half the non-platoon. Furthermore, PFA(PCA and PRA) reduces average controlling time to half the pure platoon.

Fig.11 shows average speed near the exit. This figure shows disadvantage of pure platoon and PCA compared with non platoon. In pure platoon, this causes by complexity of operations near the exit. PCA reduced the op-

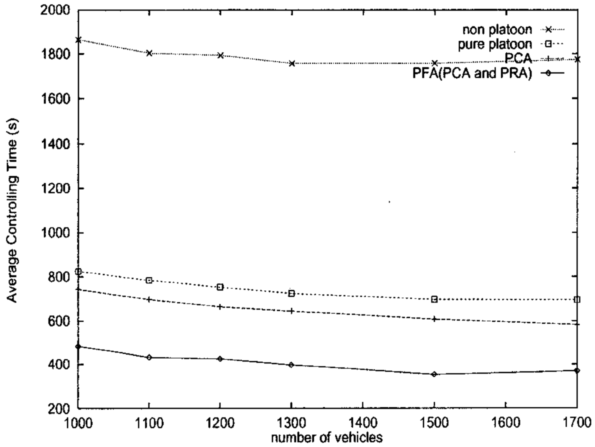

Figure 9: Average Controlling Time

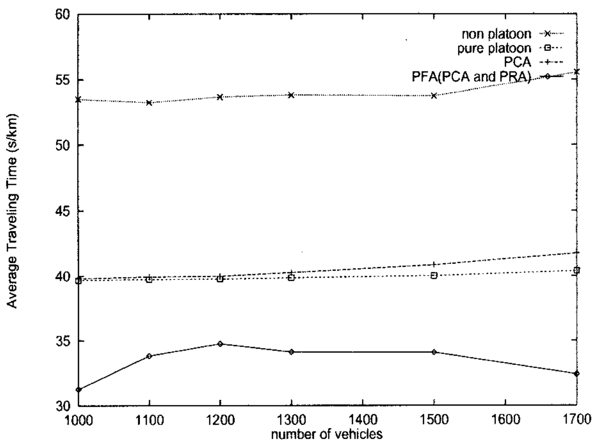

Figure 10: Normalized Average Traveling Time

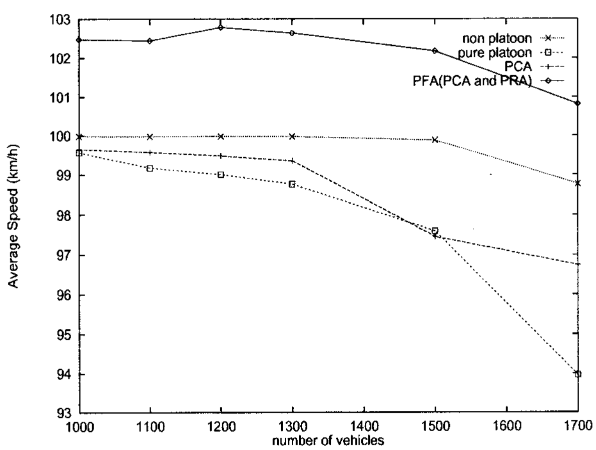

Figure 11: Average Speed near the exit at platoon lane

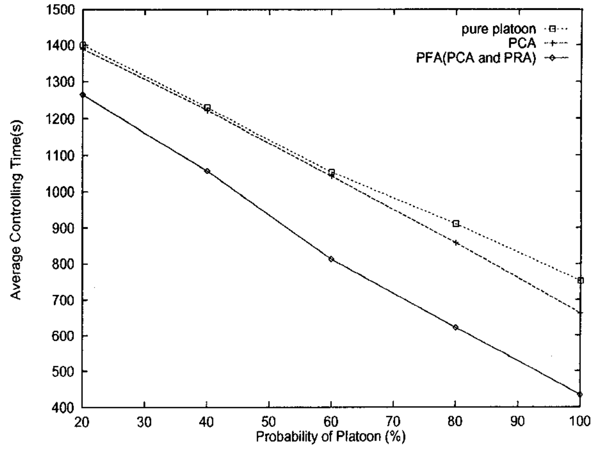

Figure 12: Average Controlling Time

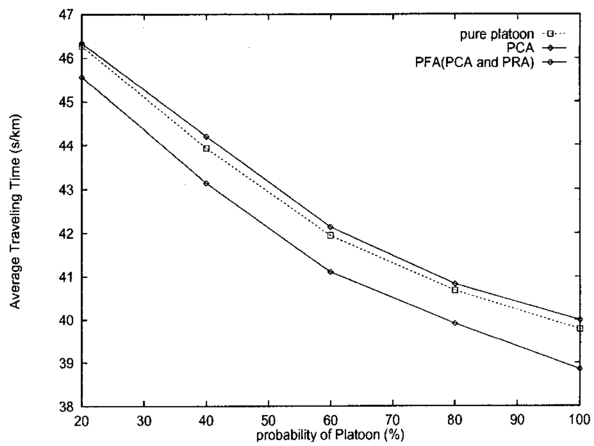

Figure 13: Normalized Average Traveling Time

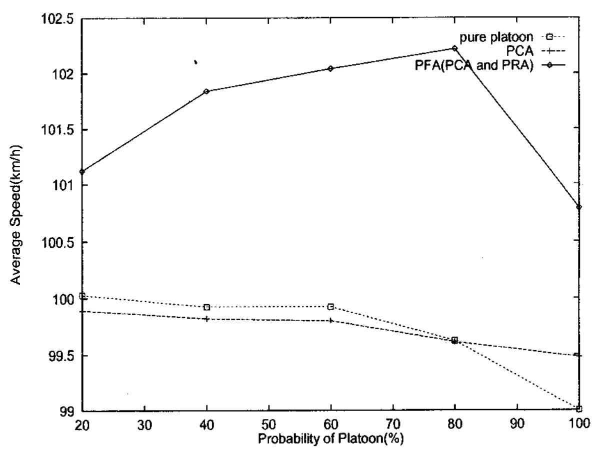

Figure 14: Average Speed near the exit at platoon lane

eration complexity, but the overheads of platoon is not avoided because each platoon cannot glow up enough. Whereas, PFA keeps the highest efficiency constantly.

Fig.12–Fig.14 shows the result of changing from the percentage of vehicles consisting platoon from 20% to 100%. The number of vehicles is 1200.

Fig.12 shows average controlling time. Fig.13 shows normalized average traveling timel . From these results, if the number of vehicles consisting platoon increases, the efficiency appeared clearly. When platoon system is not spread so much, a certain measure of effects will be expected.

Fig.14 shows average speed near the exit. There are little effect of average speed by the probability of platoon. PFA also keeps higher efficiency constantly.

By these figures, pure platoon has disadvantages near the exit. It is able to say that PCA is not enough to solve these disadvantages without using PRA.

PFA(PCA and PRA) has excellent characteristics not only near the exit but also whole road.

5 Conclusion

We proposed Platoon-Formation Algorithm considering the destination of each vehicle. From the simulation results near the exit, pure platoon makes lower efficiency of the road. Only considering destination when constructing a platoon(PCA only), the performance has hardly improved. By using PFA, the road capacity unprecedentedly increases and the comfort of drivers will really go up.

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