Freeway Cooperative Merging and Lane Changing Through V2I and V2V Communication

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ABSTRACT

The ubiquitous transportation system is a decentralized system with individual vehicular sensor nodes while the existing ITS is a centralized system in which all the data collected are sent to ITS center and all the control actions taken by the center. In ubiquitous transportation system environment, the individual vehicular nodes become a sensor and a processor at the same time, which means they are acting like small individual centers. The 2-way communication environments make more efficient control for individual vehicles possible and furthermore make it possible to monitor the individual vehicle's decisions on route choice or whatever and coordinate them to achieve the system optimal. This paper proposes a freeway cooperative merging and a cooperative lane changing schemes, which takes advantage of vehicular sensor network and V2V(Vehicle to Vehicle), V2I(Vehicle to Infra) 2-way communication environments of the ubiquitous transportation system. Algorithms for the cooperative merging and the cooperative lane changing are developed. Field trial tests are undergoing for the cooperative merging and the lane changing schemes. The proposed schemes are expected to significantly improve safety and productivity of freeway system.

Keywords: Cooperative Merging, Cooperative Lane Changing, VII, V2V Communication

INTRODUCTION

The ubiquitous transportation system (u-T system) is a decentralized system with individual vehicular sensor nodes while the existing ITS is a centralized system in which all the data collected are sent to ITS center and all the control actions taken by the center (refer to Figure 1). In u-T system environment, the individual vehicular nodes become a sensor and a processor at the same time, which means they are acting like small individual centers. So it is necessary to define the role of the center and that of the individual vehicular nodes while addressing the u-T user services.

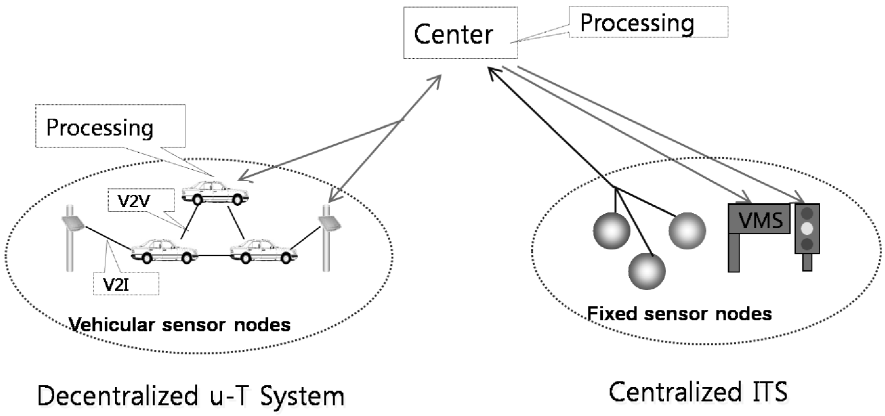


Figure 1. Ubiquitous Transportation System vs. ITS

With revolutionary advancement of sensor and wireless communication technologies, a variety of ubiquitous services are to be available. It is time to upgrade the existing traffic flow management skills by fully exploiting the ubiquitous sensor and wireless communication technologies. The advantages of ubiquitous transportation system over the existing intelligent transportation system are summarized as follows:

1. Individual vehicle level data collection
2. V2V and V2I 2-way communication environments

Figure 2 represents a hierarchical ubiquitous traffic management system. To maintain the traffic stability, role of traffic management center and each individual vehicle is defined. The traffic management center performs a platoon control through V2I communication using the optimal speed for platoon calculated based on real-time traffic flow conditions. Then minor adjustments should be made at each individual vehicle level to cope with unexpected and abrupt changes of traffic flow conditions. Former researches performed by the author addressed the center-level traffic flow management problem, which can be summarized as follows:

Firstly, collect each vehicle's position and speed data through V2I communications.

Secondly, process the collected data and produce 3-D speed, volume, density, platoon, and shockwave speed profiles.

Thirdly, verifying the traffic state and traffic flow stability based on the processed profiles mentioned above.

Fourthly, calculate optimal speed and headway for each section and for each traffic state.

Finally, advise the optimal speed and headway to drivers to V2I communications

In this paper, individual vehicle-level adaptations to cope with abrupt and minor changes of the circumstances are taken into consideration. More specifically, freeway cooperative merging and cooperative lane changing schemes are proposed, which takes advantage of vehicular sensor network and V2V, V2I 2-way communication environments. Algorithms for the cooperative merging and the cooperative lane changing are developed. And settings and scenarios for field trial tests are provided.

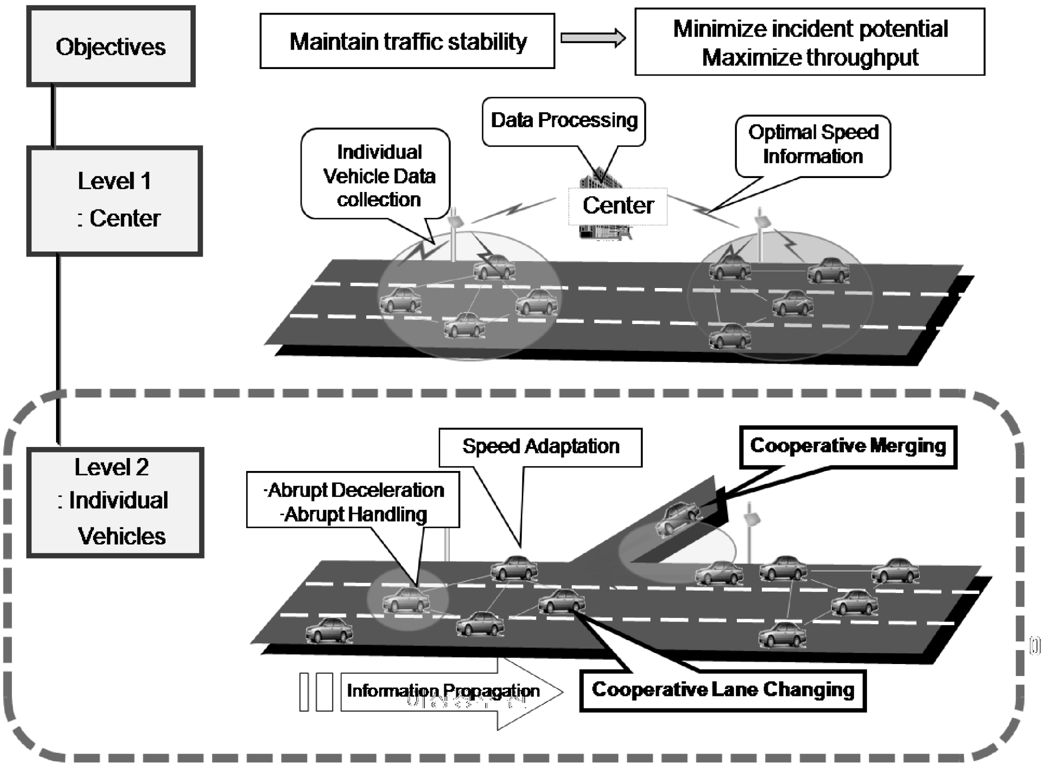


Figure 2. Hierarchical Ubiquitous Traffic Management Scheme

ALGOTIRHMS

In this section, algorithms for the cooperative merging and the cooperative lane changing are provided. In developing these two algorithms, the trade-off issue between safety and efficiency should be addressed. Field experiments to examine the sensitivity of each parameters should be performed.

Cooperative Merging Algorithm

Step 1. Feasibility Check

Input parameters: acceleration rate (0.6-0.7 m/sec^2)
min. safe headway time (3 sec)
merging point

Assumption: Speeds of the mainline vehicles remain constant.

Step 1-1. Estimate each mainline vehicles' position when the merging vehicle be at the merging point.

(1) $$l = v \times t + \frac{1}{2} a \times t^2$$

where, t = elapsed time for the merging vehicle to arrive at the merging point
v = the merging vehicle's speed
a = acceleration rate
l = the distance between the merging point and the merging vehicle's current position

(2) Solve the Eq. (1) for t,

$$t = \frac{-v + \sqrt{v^2 + 2al}}{a}$$

(3) Estimate the mainline vehicles' position changes by inserting the above t value and the mainline vehicles' speed into the Eq. (1).

Step 1-2. Identify a vehicle(Vehicle K) nearest at the merging point based on the estimated mainline vehicles' position changes.

Step 1-3. IF the Vehicle K is at the point behind the min. safe headway
THEN Go To Step 2-1 ELSE Go to Step 2-3(1).

Min. safe headway = min. safe headway time × Vehicle K's speed

Step 2. Safety Check

Input Parameter: TH1 (5km/h)
TH2 (15km/h)
Min, safe headway time for merging (6 sec)
Min. safe forward headway time for merging (2 sec)
Min. safe backward headway time for merging (4 sec)

Step 2-1. Estimate the merging vehicle's speed at the merging point and check whether the merging vehicle can attain the mainline speed.

(1) Merging vehicle's speed at the merging point

$$v_m = v + a \times t_m$$

where v_m = Merging vehicle's speed at merging point v = Current speed of the merging vehicle

t_m = Elapsed time to the merging point

(refer to Step 1-1(1) Eq.)

(2) Assuming the mainline speed remains constant, compare the estimated speed from Step 2-1(1) to the mainline speed.

Step 2-2. IF (Vehicle K's speed - v_m) < TH1

THEN (1) Optimal speed for merging = mainline ave. speed

Merging risk level = row

Optimal mainline speed = mainline ave. speed

Merging status = merging

(2) Send the merging information

Step 2-3 IF (Vehicle K's speed - v_m) $\geq$ TH2,

THEN (1) Search the next safe headway for merging after the Vehicle K.

Safe headway for merging

= min. safe headway time × mainline speed

(2) Estimate the time for the merging vehicle to arrive at the point to merge into the next safe headway.

The merging vehicle should be at the merging point after the time (t1+t2) be elapsed.

t1 = the elapsed time to the merging point

t2 = min. safe forward headway time

(3) Estimate the deceleration/acceleration rate necessary to arrive at the merging point at the right time.

$$l = v \times t + \frac{1}{2} b \times t^2$$

where, t = the Elapsed time to the merging point

v = Current speed of the merging vehicle

b = Deceleration/acceleration rate

l = the distance to the merging point

(4) Optimal speed for merging =

Refer to the deceleration/acceleration rate in Step 2-3(3)

Merging risk level = Very high

Optimal Speed for mainline =

min(Mainline ave. speed, Speed limit)

Merging Status = Merging discouraged

(5) Send the merging information.

Step 2-4. ELSE (1) Ask Vehicle K's cooperation, i.e Vehicle K's deceleration.

Vehicle K's desired speed =
the merging vehicle's speed attained at the merging point.

(2) Optimal speed for merging =
the speed attainable at the merging point
Merging risk level = high
Optimal speed for mainline =
Reduce speed to the merging vehicle's attainable speed
Merging Status = Merging expected

(3) Send the merging information.

Cooperative Lane Changing Algorithm

Step 1. Lane Changing Risk Evaluation
Input parameters:
Elapsed time to get to the target lane after lane changing t_c (2 sec)
Adjustment factor α (0.8)
min. safe headway for lane changing (6 sec)
min. safe forward headway for lane changing (2 sec)
min. safe backward headway for lane changing (4 sec)
TH3 (1 sec)

Step 1-1 Estimate the position where and the time when the Vehicle C (the lane changing vehicle) gets in the target lane.
(1) Calculate the time by the input parameter t_c
(2) Estimate the the Vehicle C's position in the target lane by the position change.

Step 1-2 Estimate the position changes for the two mainline vehicles (Vehicle 1&3) involved in lane changing, assuming mainline speed remains constant, estimate the position changes during t_c.

Step 1-3 Compare the Estimated Vehicle C's position in the target lane with the that of Vehicle 1 and 3.

Step 1-4. IF forward headway and backward headway are greater than the min. safe forward headway and min. safe backward headway, respectively,
THEN (1) Lane changing risk level = row
(2) Send the lane changing information

Step 1-5. ELSE
IF (Estimated forward and backward headways - min. safe forward and backward headways) < (TH3*Current speed)

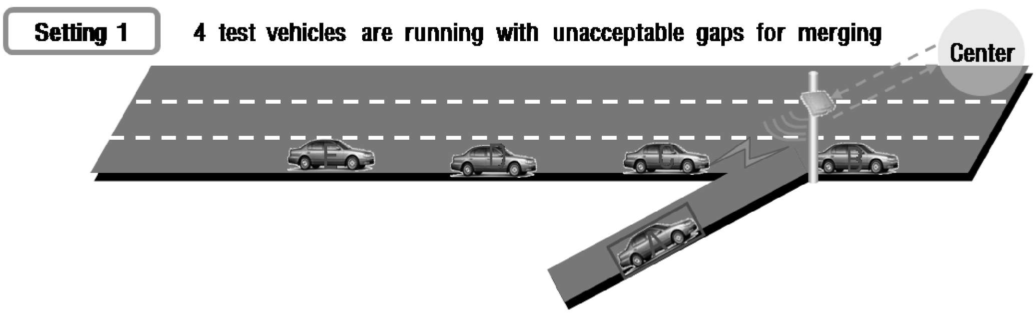
THEN (1) Lane changing risk level = medium
(2) Send the lane changing information and GO TO Step 2
Step 1-6 ELSE IF (Position Difference between the Front and/or the Back and the Vehicle C) <0
THEN (1) Risk level = Very High
(2) Send the lane changing information.
('Do not change lane')
and GO TO Step 2
ELSE (1) Risk level = High
(2) Send the lane changing information.
(Discourage the lane change)
and GO TO Step 2

Step 2. Cooperative Lane Changing Feasibility Evaluation
Step 2-1. IF risk level = medium,
THEN (1) Vehicle 1(Forward Vehicle) speeds up to the speed limit. Vehicle 3 slows down to make safe headway for lane changing.
(2) GO TO Step 1.
Step 2-2. IF risk level = high or very high,
THEN search for the next available headway and GO TO Step 1.

FIELD TRIAL TEST SCENARIOS

In this section, test settings and scenarios for the cooperative merging and the lane changing are provided. The field trial tests plan to be performed in an urban freeway in Seoul, Korea with 5 test vehicles and 5 roadside infrastructures.

Cooperative Merging Settings and Scenarios



Secnario 1

Step 1. Vehicle A – Communicating with the mainline vehicles about the 'Merging Intension'

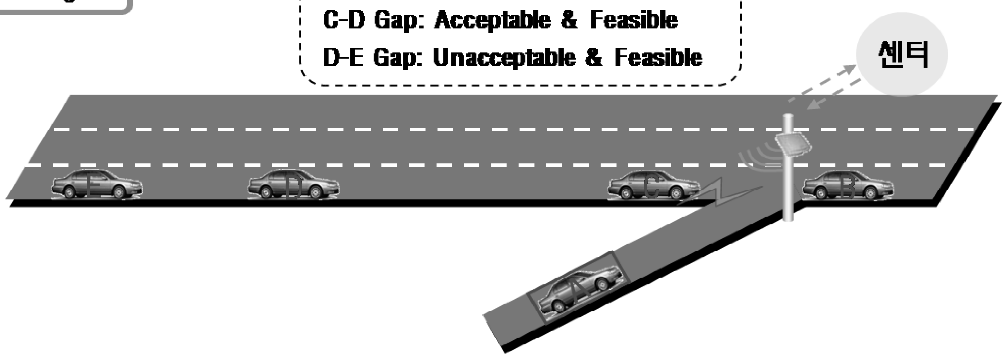
Step 2. Vehicle C – Warning message to Vehicle A to discourage using the B-C gap.

Step 3. Vehicle D – ① Decelerate to make a room for A's lane change
② Warning message for deceleration to Vehicle E
③ Message for encouraging using the C-D gap to A

Step 4. Vehicle A – Merging Maneuver

Setting 2

B-C Gap: Unacceptable & Infeasible
C-D Gap: Acceptable & Feasible
D-E Gap: Unacceptable & Feasible



Scenario 2

Step 1. Exchanging the position data with one another.

Step 2. Vehicle A – Evaluate B-C, C-D, D-E Gaps in the mainline lane.

IF Gap < Critical Gap THEN Unacceptable
ELSE Acceptable
IF the Gap can be taken for vehicle A in terms of position
THEN Infeasible ELSE Feasible

Step 3. If there exists an acceptable and feasible gap, then
If the front vehicle of the gap pass the merging point,
then GoTo Step 4
Else GoTo Step 1

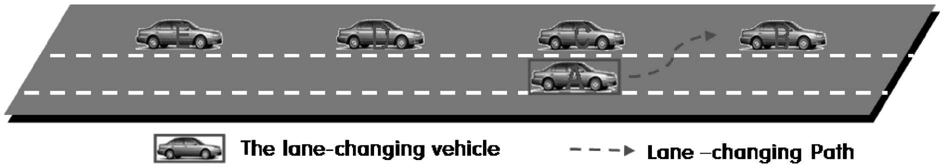
Step 4. Vehicle A – Merging Maneuver
Warning message for merging to C, D, E

Step 5. Vehicle D – Deceleration
Warning Message for deceleration to E

Step 6. Vehicle E – Deceleration

Cooperative Lane Changing Settings and Scenarios

Setting 1 4 test vehicles are running with unacceptable gaps for lane changing



Scenario 1

Step 1. Vehicle A – Communicating with the neighboring vehicles about the 'Lane Changing Intension'

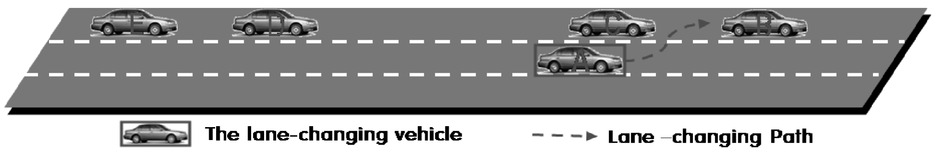
Step 2. Vehicle C – Warning message to Vehicle A to discourage using the B-C gap.

Step 3. Vehicle D - ① Decelerate to make a room for A' s lane change
② Warning message for deceleration to Vehicle E
③ Message for encouraging using the C-D gap to A

Step 4. Vehicle A – Lane Changing Maneuver

Setting 2

B-C Gap: Unacceptable & Infeasible
C-D Gap: Acceptable & Feasible
D-E Gap: Unacceptable & Feasible



Scenario 2

Step 1. Exchanging the position data with one another.

Step 2. Vehicle A – Evaluate B-C, C-D, D-E Gaps in the neighboring lanes.

IF Gap < Critical Gap THEN Unacceptable
ELSE Acceptable
IF the Gap can be taken for vehicle A in terms of position
THEN Infeasible ELSE Feasible

Step 3. If there exists an acceptable and feasible gap, then
If Vehicle A needs to wait to take the Gap, then 'Wait'
else GoTo Step 4
Else 'Wait' and GoTo Step 1.

Step 4. Vehicle A – Lane Changing Maneuver
Warning message for lane changing to C, D, E

Step 5. Vehicle D – Deceleration
Warning Message for deceleration to E

Step 6. Vehicle E - Deceleration

FUTURE RESEARCHES

This paper proposes a freeway cooperative merging and a cooperative lane changing schemes, which takes advantage of vehicular sensor network and V2V, V2I 2-way communication environments of the ubiquitous transportation system. Algorithms for the cooperative merging and the cooperative lane changing are developed. Field test settings and scenarios for the developed algorithms are provided. Field trial tests are undergoing and therefore, remains as a further research. In the future field experiments, the sensitivity analyses of each parameters should be performed to address the trade-off issue between safety and efficiency.

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