DYNAMIC SPEED CONTROL USING FREEWAY VEHICULAR SENSOR NETWORK DATA

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Abstract: This paper proposes a new freeway traffic management scheme, which takes advantage of vehicular sensor network and V2V(Vehicle to Vehicle)/ V2I(Vehicle to Infra) two-way communication environments of the ubiquitous transportation system. The proposed scheme pursues to maintaining traffic flow stability to prevent from or at least delay the flow breakdown and as a result, to maintaining the productivity. Speed control strategies according to the traffic flow states were proposed. Simulation testbed was built for simulation experiments. The simulation results showed that the proposed speed control algorithm significantly improve traffic flow condition of the simulation network. But it fails to prevent from getting congested when flow level increases although it works well to a certain level of flow. The speed control for the congested state should be incorporated in the proposed algorithm, which remains as a further research.

Key Words: Dynamic speed control, Vehicular Sensor Network, Ubiquitous Transportation System, Congestion Management

1. VEHICULAR SENSOR NETWORK ENVIRONMENTS

Under ubiquitous transportation system environments, ad-hoc networks are formed among the roadside infrastructure(s) and the neighboring vehicular sensor nodes. And then data collection and information exchanges occur through V2V(vehicle-to-vehicle) and V2I(vehicle-to-infra) communications. Data are collected for pre-defined spots and/or sections at pre-defined intervals under the existing ITS(Intelligent transportation system). However, under the vehicular sensor network environment, each individual vehicle's data are collected in a seamless manner, which makes it possible to perform more sophisticated traffic flow management at individual vehicle level.
2. PROBLEM STATEMENTS

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

The vehicular sensor network makes it possible to collect individual vehicle level data, which, in turn, makes it possible to more precisely estimate traffic flow states in real time. And based on the precise real time information about the traffic flow state, more sophisticated traffic flow management at individual vehicle or platoon level can be performed through the V2V and V2I 2-way communications.

It is crucial in traffic flow management to maintain productivity and the traffic stability at the same time especially under congested traffic conditions. Figure 2 (a) shows that traffic flow becomes unstable and even breaks down even far before traffic flow state reaches the critical density level. This implies that stable region is much narrower than it should be and the throughput is much less than the nominal capacity in real world. In this context, traffic flow management is desired to widen the stable region and/or to improve the productivity (refer to Figure 2 (b)). However, the ITS data collected and the control measures available are still very limited to explicitly address this flow management issues.

In this paper, a freeway speed control scheme taking advantage of the vehicular sensor network data is proposed to enhance the traffic flow stability and furthermore to improve the productivity.
Figure 2 Field Data and Traffic Flow Stability

3. PROSPED ALGORITHM FOR FREEWAY SPEED CONTROL

Figure 3 shows two schematic graphs of travel time changes according to various traffic flow levels based on the previous simulation experiment results performed by the author. It implies that different control objectives should be desired according to various flow states, which can be summarized as follows:

1. When flow is in normal state, speed differences among individual vehicles and/or some drivers' mal-behavior cause flow instability. This implies that speed control should be desired to achieve the fairly optimal/uniform speed distribution. On the other hand, it is concerned that the excessive control under free flow traffic state would reduce the system productivity.
2. When flow becomes critical (that is, about LOS E), vehicle platoons formed cause flow instability, which implies platoon management should be applied.
3. When flow reaches LOS F, no travel time difference exist, which implies no speed control can improve the system and demand management be applied.

The control strategies according to the various control objectives for each traffic flow states are proposed as follows: Advise the drivers to maintain the optimal speed for normal flow state, maintain the traffic flow stability for critical state, and surpress the shock wave propagation for congested state.

This paper only focuses on the traffic flow management for normal and critical states and the following algorithm steps are proposed:

- **Step 1.** Collect each vehicle’s position and speed data through V2I communications.
- **Step 2.** Process the collected data and produce 3-D speed, volume, density, platoon, and shockwave speed profiles.
- **Step 3.** Verifying the traffic state based on the processed profiles in the Step 2.
- **Step 4.** Calculate desirable speeds for each section and for each traffic state.
  - **Step 4-1.** IF Normal state, THEN Optimal speed = Greenshields' equilibrium speed for current density of each unit section.
  - **Step 4-2.** IF Critical state, THEN
    - **4-2-1.** Calculate current average density for whole unit sections
    - **4-2-2.** Find the Greenshields' equilibrium speed for the average density.
4-2-3. Desired speed = the Greenshields' equilibrium speed for whole unit sections

4-2-4. Adjust the desired speed based on the following constraints:
   a. Difference between the current speed and the desired speed for each unit sections should be less than 10 km/h.
   b. Speed difference between the two consecutive time intervals for a given section should be less than 10 km/h.
   c. Speed difference between the two consecutive unit sections for a time interval should be less than 10 km/h.

Step 5. Advise the optimal speed to drivers to V2I communications.

4. SIMULATION TESTBED

4.1 Methodology

Figure 4 represents the simulation testbed built for simulation experiments to evaluate the speed control algorithm proposed in this paper.

VISSIM simulation model cannot control individual vehicles' speed freely. Therefore, C# programming codes are written for the data processing and the optimal speed calculation procedures of the proposed algorithm. Some parts of the C# codes written are also shown in the Figure 5. Through COM(Component Object Model) interface, individual vehicles' data are fed into the C# code programmed. And then, the calculated optimal speeds for individual vehicles are fed into the VISSIM model and finally, the speed control effects are evaluated.
4.2 Simulation Network and Scenario

Simulation experiments were performed with a 14.2 km section between Osan IC and Suwon IC of the Kyungbu Expressway, which is shown in Figure 5. Three traffic patterns in Figure 6 are applied in the simulation experiments.

5. SIMULATION EXPERIMENT RESULTS

Figure 7 shows travel time changes before and after speed control when traffic is under the normal state. It is shown that speed control has slowed the travel time growth down. But travel time grows even after control when traffic flow increases and the density level reaches around 28 pcp/hpl. This implies that it is desired to switch the speed control as a critical state one when the density is over 28 pcp/hpl.
Figure 8 to 10 are simulation experiment results for scenario 1, 2, and 3, respectively. It is shown from the before and the after speed and density profiles, that speed profiles is improved and at the same time, high density region is significantly reduced after control. Figure 11 shows the travel time changes before and after speed control. Speed control by the proposed algorithm fails to prevent from getting congested when flow level increases although it works well to a certain level of flow. The speed control for the congested state remains as a further research.

![Travel Time Changes before and after Control](image)

Figure 7. Travel Time Changes before and after Control (Normal State)

![Density Profiles (2-D)](image)
![Density Profiles (3-D)](image)
![Speed Profile (2-D)](image)
![Speed Profile (3-D)](image)

Figure 8. Speed and Density Profile Changes (Scenario 1)
Figure 9. Speed and Density Profile Changes (Scenario 2)

Figure 10. Speed and Density Profile Changes (Scenario 3)

Figure 11. Travel Time Change before and after Control
6. CONCLUDING REMARKS

The vehicular sensor network and 2-way communication environments make more efficient control for individual vehicles and/or platoons possible. This paper addressed the traffic flow stability issue in traffic flow management by taking advantage of the ubiquitous transportation system environments.

Speed control strategies according to the traffic flow states were proposed. Simulation testbed, which connects C# codes for the proposed algorithm and VISSIM model through COM interface, was built for simulation experiments. The simulation results showed that the proposed speed control algorithm works well and improve traffic flow. But it fails to prevent from getting congested when flow level increases although it works well to a certain level of flow. The speed control for the congested state should be incorporated into the proposed algorithm, which remains as a further research.

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