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Development and Comparison of Centralized and Decentralized ATIS Models with Simulation Method

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요 약

교통체증은 도시지역에서 심각한 경제적, 사회적 비용을 초래하는 원인으로 간주되고 있다. ITS기법은 첨단 센싱, 컴퓨팅, 그리고 통신기술을 이용해 교통체증을 경감시킬 수 있는 훌륭한 수단이다. 본 연구는 차량과 주변 인프라 그리고 차량 간의 무선통신을 통한 중앙제어식 그리고 분산식 첨단통행자정보시스템의 프레임워크를 제안하고 전형적인 6X6 도시형 도로망에서 그 효과를 시뮬레이션 기법을 이용하여 분석하고자 한다. 본 논문의 연구결과로서는 교통류, 무선통신 라디오 레인지 그리고 통신차량의 보급률 등에 따라 제안된 첨단통행자정보시스템은 교통사고로 야기된 정체지역을 우회할 수 있는 최적의 노선을 제공함으로써 운전자의 통행시간을 줄여주는 효과를 보였다. 다양한 연구 환경에서도 중앙제어식 그리고 분산식 첨단통행자정보시스템은 거의 동일한 효과를 보였는바, 분산식 첨단통행자정보시스템은 고가의 건설비와 설치 운영비를 요구하는 중앙제어식 첨단통행자정보시스템을 대신할 수 있는 시스템으로 기대된다.

Abstract

Traffic congestion is a source of significant economic and social costs in urban areas. Intelligent Transportation Systems (ITS) are a promising means to help alleviate congestion by utilizing advanced sensing, computing, and communication technologies. This paper proposes and investigates a basic and advanced ITS framework Advanced Traveler Information System (ATIS) using wireless Vehicle to Roadside (Centralized ATIS model: CA model) and Vehicle to Vehicle (DeCentralized ATIS model: DCA model) communication and assuming an ideal communication environment in the typical 6X6 urban grid traffic network. Results of this study indicate that an ATIS using wireless communication can save travel time given varying combinations of system characteristics: traffic flow, communication radio range, and penetration ratio. Also, all tested metrics of the CA and DCA models indicate that the system performance of both models is almost identical regardless of varying traffic demand and penetration ratios. Therefore, DCA model can be a reasonable alternative to the fixed infrastructure based ATIS model (CA model).

Key words : Advanced traveler information system (ATIS), vehicle to roadside communication, vehicle to vehicle communication, automatic incident detection (AID) algorithm, driver behavior model

Ⅰ. Introduction

According to the Urban Mobility Report developed by the Texas Transportation Institute in 2007 [1], economic and social costs (i.e., prolonged travel time and wasted fuel) attributable to traffic congestion in the leading cities in America has continued to increase. For example, in the included urban areas estimated 4.2 billion hours and 2.9 billion gallons of fuel were consumed due to traffic congestion. These

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problems are drawing increasing attention from both private and the public entities. To address congestion many transportation practitioners and engineers are focusing on increasing the efficiency of the existing traffic system rather than new construction. Over the past several decades, Intelligent Transportation Systems (ITS) have emerged as a promising means to achieve this increased system efficiency, by accurately monitoring traffic states, computing and executing optimized alternative traffic strategies, and distributing up to date traffic information to drivers. ITS encompasses a broad range of wireless and wire line communication based information and advanced technologies integrated into the transportation system infrastructure and on board vehicles with the objective of relieving traffic congestion, improving safety, and enhancing traffic network productivity. With the ongoing improvements and decreasing costs in wireless communications many have been led to explore wireless ITS solutions such as dynamic Advanced Traffic Management System (ATMS) and dynamic Advanced Traveler Information System (ATIS) utilizing Vehicle to Roadside (V2R) communication and Vehicle to Vehicle (V2V) communication.

This paper aims to propose, develop, and evaluate a potential architecture of dynamic ATIS by directly integrating the communication model, ITS database management process, and dynamic routing process into a vehicle simulation (i.e., basic ATIS model) under ideal communication environment like no signal drops and no data loss while communicating and investigate its basic characteristics. Furthermore, three more complementary operational rules to enhance the system performance such as autonomous automatic incident detection (AAID) algorithm, minimum sample size, and driver's route selection behavior are proposed as well (i.e., advanced ATIS model). A commercial off the shelf (COTS) microscopic traffic simulation model (i.e., VISSIM and VISSIM COM) [2, 3] is utilized for developing a dynamic ATIS architecture coupled with wireless communication, taking into account two types of ATIS application deployments such as Centralized and DeCentralized traffic information systems (which are referred to as CA and DCA models hereafter). The performance of the proposed ATIS models is investigated in the typical 6X6 urban grid traffic network with the non-recurrent traffic state like traffic incident in the sensitivity of average travel time savings of instrumented vehicles to the varying underlying factors such as traffic flow, communication radio range, and penetration ratio. In addition, this paper attempts to distinguish the difference of CA and DCA models in the system performance and operational characteristics from the traffic engineering perspective. This paper is organized as follows: Section Ⅱ describes the ATIS model development process, the experimental design and simulation outputs of CA and DCA models in the typical urban grid traffic network are presented in Sections Ⅲ and Ⅳ, respectively. Lastly, Section Ⅴ provides conclusions and future research issues.

Ⅱ. Development of ATIS Models

1. Basic ATIS Model

Centralized and decentralized ATIS models using vehicle communication (CA and DCA models) are proposed. The CA model is assumed to utilize a traffic information center (TIC) while the DCA model depends solely on traffic data shared between instrumented vehicles. Both models are implemented with three fundamental tasks (i.e., communication, travel time database update, and route update).

1) Communication

The Vehicle Communication Module (VCM) contains the Vehicle to Roadside (V2R) and Vehicle to Vehicle (V2V) communication logic. For this effort a simplified communication model is developed under an idealized communication environment. Future efforts will improve the VCM, incorporating more realistic communication related parameters configured for a specific region. A separate communication architecture is utilized for CA and DCA models.

The CA model exploits wireless communication between roadside communication units (RSU) and participating vehicles [4] and it is assumed that the entire traffic network is within the communication range of the RSUs and the TIC. Traffic data is sent from participating vehicles to the TIC on a periodic basis (i.e., 1 second in this paper) to update the central database and route calculation algorithm. On the other hand, the DCA model utilizes V2V communication only. At any update interval a communication link is dynamically established when participating vehicles are within radio range. The implemented DCA model identifies interconnected groups of vehicles (i.e., communication group formation process) and instantaneous data exchange is executed through multi hop communication within these groups (i.e., data dissemination process). The data propagation scheme used is broadcasting with flooding, where data communication is conducted within an interconnected group of vehicles without direct consideration of communication routing issues [5].

2) Travel Time Database Update

The efficient management of the spatial and temporal travel time information is a core element of an CA and DCA models. This travel time information is stored in a module called the space time memory residing in the TIC or on board each participating vehicle. As the participating vehicles are traversing the network, they save travel time data to their local space time memory and communicate with the RSUs or neighboring participating vehicles. Using the travel time data gathered, the central database or on board databases are updated each system update time interval, allowing for the new calculation of revised vehicle route information.

The CA model provides some smoothing of the travel time data using a moving average approach. In this implementation time is divided into uniform time interval bins (i.e., 3 minutes in this paper), starting at time zero and continuing throughout the experiment. At any time bins in the simulation run an estimated link travel time is the average of the travel time aggregated over the current time bin and the three previous bins.

The database update method in the DCA model is similar to that of the CA model but the primary difference is that individual participating vehicles in DCA model autonomously executes database updates and route selection on board the vehicle, utilizing received data.

3) Route Update

The TIC or the individual participating vehicles will recalculate the optimal route from their current position to its final destination at the end of each time bin, implementing Dijkstra's searching algorithm [6] with the estimated travel time data processed and transferred from the travel time database update step. If newly calculated route is different from the vehicle's original route the vehicle will change routes. This is the equivalent to a traveler selecting their initial route to work, receiving new information during their trip (e.g., from a radio traffic report), and changing their route based on that data (i.e., en route traffic guidance system).

2. Advanced ATIS Model

This paper suggests three complementary rules to enhance the performance of the proposed dynamic ATIS models (i.e., autonomous automatic incident detection (AAID) algorithm, minimum sample size rule, and simple driver's route selection rule). These functions are aimed to not only save more travel by detecting the non recurrent traffic states in more timely manner (efficiency) but also improve reliability of the system guided route information and robustness to negligible traffic state variation.

1) Autonomous Automatic Incident Detection (AAID) Algorithm

Unlike the general automatic incident detection (AID) algorithms taking advantage of the aggregated sensor data and employed by the centralized traffic information system, this paper proposes a new method to autonomously recognize the non recurrent traffic states, utilizing the historical travel time saved in the associated database. In the case where a participating vehicle stays on a traffic link multiple times (which is referred to as K factor hereafter) longer than the average link travel, it will issue and propagate the traffic alert message to the upstream vehicles which will instantly update the downstream traffic states and search for the alternative routes to the destination. The user defined K factor is critical in determining the performance of the ATIS using vehicle communication. That is, the low factor values may be too sensitive to the insignificant traffic state variation, particularly in the signalized traffic network, resulting in too many traffic alerts (i.e., false alarms) and also too high factor values will delay the timely update of the adverse traffic states.

2) Minimum Sample Size

Since traffic information systems with the proposed ATIS model using vehicle communication are utilizing travel time information to find the best route from the current location to the final destination, they are required to secure a minimum number of network monitoring vehicles for the reliable travel time estimation. This paper applies the broadly accepted minimum sample size function in <Eq. (1)> [7].

$$SS_{j,t}^{i} = (T \times \frac{S_{j,t}^{i}}{\epsilon_{j,t}})^{2} \qquad (1)$$

where:

$SS_{j,t}^{i}$ = required sample size of vehicle i for link j and time bin t

T = t-value

$S_{j,t}^{i}$ = standard deviation of travel time records of vehicle i for link j and time bin t

$\epsilon_{j,t}$ = user-specified allowable error for link j and time bin t

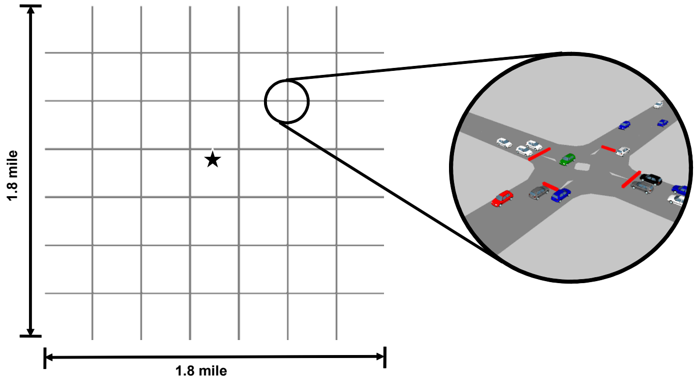
3) Driver Behavior Model

ATIS is increasingly being recognized as a potential strategy for influencing driver behavior regarding route choice, trip making, time of departure, and mode choices. The provision of real time travel information allows drivers to make informed travel decisions and has the potential to improve network efficiency, reduce congestion, and enhance environmental quality. The successful implementation of these systems, however, will depend to a large extent on understanding how drivers adjust their travel behavior in response to the information received [8].

It is noted that small differences in the travel time between routes can trigger unnecessary re routing. Therefore, a minimum time savings threshold is applied for a vehicle to choose a new route [9]. The advanced ATIS model using vehicle communication employs a boundedly rational switching rule, stating that drivers change their route only if the improvement in the remaining travel time exceeds some indifference band (which is referred to as I factor hereafter in this paper) of travel time saving.

Ⅲ. Experimental Design

<Fig. 1> provides the typical 6X6 urban grid traffic network and an eastbound traffic incident (the dark star) is located in the center of the network with one



〈Fig. 1〉 Notional typical 6X6 urban traffic network
Note: zoomed in circle = a typical intersection controlled by the traffic signal

vehicle release every 90 seconds in effect from 1000 second to 2000 second. Each simulation experiment is run for 4800-second (i.e., 1200-second warm up and 3600-second main runs) with the reported results the average of ten replicates. Traffic signal timing parameters uniformly applied to all intersections are set to 2 minute cycle length, split phase (i.e., all through movements are assigned 41-second and left turn vehicles 11-second effective green time, respectively), and 0 second offset. All links are one lane with left turn lane and link length is 382m and 183m for the left turn bay. The approximate link travel time with no traffic signal effect is 30 second.

The parameter values of K and I factors are 3 and 20% for AAID algorithm and driver behavior model and the minimum sample size is 2 for each links. Even though these parameters should be defined with sensitivity analysis, the rational or existing parameter values suggested from the previous research have been adopted in this paper [10]. The sensitivity analysis of the parameters with the system enhancing functions will be conducted in the author's other papers. In addition, three underlying system parameters are set to 300vph and 514vph for traffic flow, 250m, 375m, and 500m for communication radio range, and 10% to 50% in 10% increment for penetration ratio. Average travel time savings of participating, non participating, and (instant) re routing vehicles are exploited as metrics to evaluate the system performance.

IV. Results and Analysis

<Table 1> shows the average travel time savings of participating and non participating vehicles for two traffic flow cases (i.e., 300vph and 514vph) and 500 meter communication radio range of the CA and DCA

〈Table 1〉 Average travel time savings of vehicles by ATIS model type

Penetration Ratio	Participating vehicle (sec./veh.) (a)				Non-participating vehicle (sec./veh.) (b)			
	300vph		514vph		300vph		514vph	
	CA	DCA	CA	DCA	CA	DCA	CA	DCA
10%	1.8	1.7	2.1	2.0	0.2	0.2	0.4	0.4
20%	2.4	2.5	4.2	4.2	0.4	0.4	1.7	1.7
30%	2.9	2.9	5.2	5.3	0.9	0.9	2.9	3.0
40%	3.3	3.2	6.3	6.3	0.7	0.7	3.5	3.4
50%	2.9	3.1	7.9	7.8	1.1	1.1	5.2	5.2

models with varying penetration ratios. <Table 1> indicates the identical pattern of travel time savings regardless of ATIS model types. That is, higher flow rates and penetration ratios result in a higher average travel time savings for participating and non participating vehicles. Travel time savings are generated from the traffic incident involved re routing of participating vehicles. While the travel time savings of participating vehicles result from the vehicle re routings to avoid the traffic incident route (<Table 1> (a)), non participating vehicles also saved their time due to the reduced delay of the traffic incident involved vehicles (<Table 1> (b)).

Interestingly, since participating vehicles under the non recurrent traffic state perform their update process at the moment traffic congestion messages are received, all routes are instantly updated. Thus, separating the (instant) re routing participating vehicles contributing to travel time savings, <Table 2> reveals that both ATIS models have the same patterns in the number of re-routing vehicles and travel time savings. Also, even though number of (instant) re routing vehicles in 300vph case is much less than that of 514vph case (<Table 2> (a)) the former case seems to save more time per instantly re routed vehicle than the latter case on average (<Table 2> (b)) because in the lower demand case fewer vehicles re-routed, most of which during the initial period after the incident when time savings was the most significant. In the higher demand case re routing also occurred during this initial time period but also during less system efficient time periods after the incident is resolved and residual congestion effects still existed. This issue will be addressed more specifically in the author's other papers.

Ⅴ. Conclusions and Future Research

This paper introduced the fundamental framework of an ATIS model using wireless communication under centralized and decentralized data processing assumptions. Key factors on the performance of ATIS model using wireless communication in the typical 6X6 urban grid traffic network were investigated. Participating vehicles communicate travel time updates with roadside units (RSUs) or neighboring participating vehicles. Using the travel time data gathered in the central database or on board databases are updated, allowing for the calculation of revised routing information. Furthermore, this paper proposed three more complementary rules (i.e., AAID algorithm, minimum sample size function, and simple driver behavior model) to enhance the system performance by detecting the non recurrent traffic state in more timely manner, improving reliability of observed traffic data and robustness to the minor traffic state variation.

To evaluate the ATIS models with wireless communication the 6X6 urban grid traffic network was constructed and implemented using an commercial off

〈Table 2〉 Number and average travel time savings of (instant) re-routing participating vehicles by ATIS model type

Penetration Ratio	Number of re-routing vehicles (a)				Average travel time savings (sec./veh.) (b)			
	300vph		514vph		300vph		514vph	
	CA	DCA	CA	DCA	CA	DCA	CA	DCA
10%	6.5	6.4	20.0	19.7	173.0	174.7	145.8	148.7
20%	14.7	15.2	52.5	52.8	247.7	242.7	163.1	163.1
30%	24.8	25.1	74.8	75.0	239.0	237.6	174.7	177.8
40%	32.9	34.3	97.4	97.1	277.1	265.7	197.7	200.9
50%	43.8	46.2	126.3	127.2	250.4	238.3	201.4	200.7

the shelf (COTS) microscopic simulation model, VISSIM and VISSIM COM, assuming an ideal communication environment with entire traffic network coverage of RSUs and no signal interference and no data loss during the communication process. Included in the experimental design was the impact of an incident.

The most significant distinction between the CA and DCA models is the location where the system is updated and data size to be used for the system update. Additionally, the CA model requires expensive infrastructure investments and operational cost with the limited scalability confined to the urban area. In spite of the fundamental difference, all tested metrics of the CA and DCA models indicated that their system performance in the average travel time savings is almost identical regardless of varying traffic demands and penetration ratios. Therefore, the decentralized ATIS model using V2V communication system can be a reasonable alternative to the fixed infrastructure based ATIS model.

As part of this investigation methods more efforts should be made to improve the communication model with more realistic communication related parameters. Also, this paper employs 3 minute system update time interval and aggregated travel time over the current and previous three time bins to estimate and predict the short term traffic state information like travel time. The impact of these design parameters on system performance should be investigated. Lastly, the sensitivity analysis of the parameter values of system enhancing functions like K and I factors should be conducted.

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