시뮬레이션기법을 통한 차량 간 통신을 이용한 첨단교통정보시스템의 효과 분석 (도시 도로망을 중심으로)

A Simulation-Based Investigation of an Advanced Traveler Information System with V2V in Urban Network

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목차

Key Words : 첨단교통정보시스템, 차량 간 통신, 미시적 시뮬레이션 모델, 동적경로안내시스템, 자동유고감지알고리즘
Advanced Traveler Information System, Vehicle-to-Vehicle Communication, Microscopic Simulation Model, Dynamic Route Guidance System, Automatic Incident Detection Algorithm

요약

최근 보다 경제적이고 쉽게 적용이 가능한 차량간 무선통신과 같은 첨단 기술들은 고비용의 교통시설과 미래의 교통수요에 대한 공간적 시스템 확장이 제한적인 고속도로에서 주로 시행되고 있는 중앙제어식 인프라기반 교통정보시스템의 가능한 대안으로 간주되고 있다. 본 논문은 차량간 무선통신을 이용한 분산식 첨단교통정보시스템을 개발하고 제안된 시스템의 효과 (운전자의 통행시간단축)를 향상시키는 세가지 보조기능(독립자동유고감지알고리즘, 실험차량 샘플 모델, 운전자행태 모델)을 소개하고자 한다. 그리고 전형적인 6X6 도시형 도로망에서 미시적 시뮤레이션모델(VISSIM)을 이용해서 세가지 중요한 패러미터(교통류, 무선통신 라디오 레인지, 통신차량의 보급율)에 따른 그 효과를 교통사고 시나리오에서 평가하고자 한다. 본 논문의 연구결과로는 세가지 시스템 패러미터가 증가함에 따라 보다 많은 무선통신 차량이 교통데이터 전송에 관련되었고 데이터전송 속도도 더 빨라짐을 보였다. 또한 통신차량들은 동적으로 현재의 교통상황 파악과 교통사고로 야기된 정체지역을 우회하는 최적의 경로를 탐색함으로써 운전자의 통행시간을 단축시키는 결과를 보였다. 교통사고로 인한 혼잡교통류 상황에 순간적으로 반응(통행시간 데이터베이스 갱신과 최적 경로 탐색)하는 차량들을 중심으로, 상대적으로 교통량이 적은 상황에서는 보다 시스템 효율적인 시간대에 운전자들이 경로를 변경하는 행태를 보인 반면에 교통량이 많은 상황에서는 많은 운전자들이 덜 효율적인 시간대, 예를 들면 교통사고가 해소된 후에도 경로를 변경하는 경우가 목격되었다. 따라서 차량당 평균통행시간단축은 교통수요와 밀접한 관계를 보였다. 그리고 실제 교통사고 시간 동안 교통사고의 직접적인 영향에 의해서 경로를 변경하는 통신차량들을 제외하면 도로망에 진입하는 차로에 있는 통신차량이 도로망내에 있는 다른 통신차량보다 통행시간이 짧은 것으로 나타났다. 또한 교통사고지점의 위치와 방향은 경로변경차량의 공간적인 분포를 결정하는 것으로 나타났다.

More affordable and available cutting-edge technologies (e.g., wireless vehicle communication) are regarded as a possible alternative to the fixed infrastructure-based traffic information system requiring the expensive infrastructure investments and mostly implemented in the uninterrupted freeway network with limited spatial system expansion. This paper develops an advanced decentralized traveler information System (ATIS) using vehicle-to-vehicle (V2V) communication system whose performance (drivers' travel time savings) are enhanced by three complementary functions (autonomous automatic incident detection algorithm, reliable sample size function, and driver behavior model) and evaluates it in the typical 6X6 urban grid network with non-recurrent traffic state (traffic incident) with the varying key parameters (traffic flow, communication radio range, and penetration ratio), employing the off-the-shelf microscopic simulation model (VISSIM) under the ideal vehicle communication environment. Simulation outputs indicate that as the three key parameters are increased more participating vehicles are involved for traffic data propagation in the less communication groups at the faster data dissemination speed. Also, participating vehicles saved their travel time by dynamically updating the up-to-date traffic states and searching for the new route. Focusing on the travel time difference of (instant) re-routing vehicles, lower traffic flow cases saved more time than higher traffic flow ones. This is because a relatively small number of vehicles in 300vph case re-route during the most system-efficient time period (the early time of the traffic incident) but more vehicles in 514vph case re-route during less system-efficient time period, even after the incident is resolved. Also, normally re-routings on the network-entering links saved more travel time than any other places inside the network except the case where the direct effect of traffic incident triggers vehicle re-routings during the effective incident time period and the location and direction of the incident link determines the spatial distribution of re-routing vehicles.

Ⅰ. Introduction

Intelligent Transportation System (ITS) is a promising means to mitigate traffic congestion and improve traffic safety. ITS encompasses a broad range of wireless and wired 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. Advanced Traffic Management System (ATMS) and Advanced Traveler Information System (ATIS) are typical ITS applications that can be implemented to improve traffic network efficiency and safety in the urban area. Such systems are supported by sophisticated technologies such as vehicle detectors, Global Positioning Systems (GPS), communication devices, and roadside or in-vehicle visual display devices. ATIS application deployments may be considered in two broad categories: fixed (typically with centralized control) and dynamic infrastructure-based traffic information systems, defined according to the mobility of physical infrastructure collecting data and relaying the collected and processed traffic data, scope of beneficiary, and source of construction and operating cost. The ATIS model using Vehicle-to-Vehicle (V2V) communication system could consist of three key system components: vehicle communication, on-board database management strategy and Dynamic Route Guidance System (DRGS). It has been seen that many researchers have found that both communication system and transportation factors affect the communication performance (Xu and Barth, 2004; Wischhof *et al.*, 2005). Aggregation and estimation methods of on-board traffic database is also important element for the overall system performance (Xu and Barth, 2006), and most DRGSs using V2V communication system improves the traffic mobility (Krajzewicz *et al.*, 2008). In order to improve the traffic information system efficiency and reliability many traffic engineers and practitioners implemented and evaluated diverse complementary schemes like the Automatic Incident Detection (AID) algorithms for the quick response to traffic incident with less erroneous alerts (Guin, 2004; Petty *et al.*, 2002), minimum sample size of the real-time traffic data, particularly, collected from probe vehicles (Srinivasan and Jovanis, 1996), and realistic driver's route choice model (Chen and Mahmassani, 1991; Ben-Akiva and Bergman, 1984). However, these research efforts have predominately been centered on ATIS applications using fixed infrastructure-based traffic information system and most system components and complementary schemes have been partially studied and investigated mainly in the freeway network, so a comprehensive ATIS model using V2V communication system including all aforementioned functions needs to be developed and tested in relatively complicated signalized traffic network. Also, most research efforts on V2V communication system have been made with the simulation method due to limitation of complete physical system development and inability to secure sufficient market penetration ratio of the instrumented vehicles.

This paper is the extension of the author's research efforts on the development and evaluation of ATIS framework using V2V communication performed in the simple traffic network (Kim, 2011), which provided the limited understanding of the system characteristics. Therefore, the objectives of this paper are to incorporate many of these proposed efficiency improvements into an autonomous decentralized traffic information system to investigate the performance of the ATIS model using V2V communication system in the typical urban gird traffic network characterized with traffic signal, and to develop a test bed of the ATIS model using V2V communication system by employing the off-the-shelf microscopic simulation model (i.e., VISSIM (PTV, 2009a; PTV, 2009b)) emulating the simple and ideal communication conditions and integrating communication and traffic mobility models. Moreover, this paper highlights the difference of the system efficiency and performance (i.e., average travel time savings) and builds the general system characteristics with temporal and spatial analyses based on the experiments in the simple and large traffic networks from the traffic engineering perspective.

Ⅱ. Literature Review

1. V2V Communication-Related Research

Recently, much of the V2V communication research has been focused on proposing, developing, and evaluating effective and efficient communication protocols. Also, as the communication nodes are moving in the traffic network with high speed interactions with surrounding vehicles, significant research has been dedicated to studying the effect of transportation-related factors on the communication performance.

Michael and Nakagawa (1996) evaluated the communication performance of single-hop and multi-hop data communication in terms of the amount of received information for a given communication radio range, using simulation method and they found that communication radio range is a function of transmitter power, receiver sensitivity and type of wireless transmission media (microwave, infra-red and so on) and multi-hop always delivers more information than single-hop communication. Hui and Mohapatra (2005) performed experimental tests with specially designed communication equipment or instrumented vehicles to gain better insights into the relationship between communication parameters and performance. They found that packet loss is much higher in vehicular communication than in the static communication scenario. Furthermore, communication throughput degrades with the number of hops traversed.

Other research efforts focused on the effect of transportation-related parameters (e.g., traffic congestion level, traffic density, traffic geometries, vehicle speed, penetration ratio, etc.) on communication performance (i.e., vehicle communication connectivity, temporal and spatial data propagation, etc.) using simulation and analytical methods. Wu *et al.* (2005) found that traffic density, penetration ratio, vehicle speed, and relative speed are important factors influencing the efficiency and velocity of information propagation. These findings have been obtained from the freeway experiments with the simulation method. Yang (2003) concentrated more on roadway geometry and concluded that weak node connectivity within one driving direction can be overcome by the inclusion in the communication hops of vehicles traveling in the opposing direction, that multi-lane traffic within the same direction improve end-to-end transmission delay, and that the bandwidth/data rate requirements for the instrumented vehicles in an urban arterial streets environment are relatively higher than that of freeway networks due to the complex network configuration and high density of vehicles distributed within the two dimensional space.

A general finding from these efforts is that traffic information systems using V2V communication require more robust communication algorithms and protocols adaptable to various communication environments to achieve the maximum performance under heavy traffic demand conditions by transmitting and receiving bulky traffic information through multi-hop communication.

2. Integrated Simulation Models

Since individual instrumented vehicles act as mobile communication nodes in the traffic network at high speed, the communication link established when two mobile communication nodes meet may quickly be broken due to the vehicle's moving out of range, and also they self-organize to form a communication network without the need for infrastructure, so it is difficult to intentionally route another communication node within radio range (Hormann *et al.*, 2004) and it is necessary to simulate vehicle movement, radio propagation, routing protocol and media access control (MAC) protocol behavior in the dynamic traffic information system. Fortunately, microscopic traffic models, radio propagation models, and wireless system models are all currently available, but need to be combined and integrated with new and specific Vehicular Ad Hoc Network (VANET) protocols and respective applications (Eichler *et al.*, 2005). Accordingly, seminal research has been conducted to overcome the addressed concerns by developing integrated simulation model with traffic mobility and wireless communication simulators. Eichler *et al.* (2005) developed a simulation model integrated with traffic simulator, CARISMA, and network simulator, NS2. They proposed four coupling methods to pursue the synchronized data exchange between them. Also, they plan to replace the traffic simulator with VISSIM due to its more detailed and realistic representation of vehicle mobility. Wu *et al.* (2004) used a federated approach to integrate a traffic simulator, CORSIM, and a network simulator, QualNet and tested their new data dissemination algorithm (MDDV, a Mobility-centric Data Dissemination algorithm intended for Vehicular networks) and analytical models for the spatial data propagation in VANET environment. Kim *et al.* (2007; 2008) constructed a simulation framework for V2V communication with traffic simulator, PARAMICS, and network simulator, QualNet and used the integrated model as one component of a traffic information system. Interestingly, Krajzewicz *et al.* (2008) added the communication module to the mobility simulation model (i.e., SUMO) and Yang (2003) incorporated a simplified communication function into the traffic simulator, PARAMICS. In fact, the requirement of the intensive computational resources to constantly trace time and location of all instrumented vehicles and maintain heavy predictive input information for the large network is a big challenge to overcome in the integrated simulation model.

Unlike other simulation models integrating existing mobility and communication simulators, this paper develops a framework of a dynamic traveler information system using V2V communication by incorporating the communication capability into the off-the-shelf microscopic simulation model, VISSIM, under an ideal communication environment (i.e., no signal interference and no data loss during data communication), focusing on the investigation of the transportation system performance (i.e., drivers' travel time savings) from the traffic engineering perspective, rather than the communication performance.

Ⅲ. Development of Atis Model Using V2V Communication

As mentioned earlier, the proposed ATIS model using V2V communication in this paper is the extended and more generalized version of the earlier efforts (Kim *et al.*, 2009; Kim, 2011) by directly integrating a communication modeling capability into a transportation microscopic simulation model. Most components required to implement the proposed ATIS model using V2V communication have been introduced in (Kim, 2011), so this section primarily describes the newly added operational improvement for the large traffic network.

Unlike the simple traffic network employed in (Kim, 2011) constituted with two one-way routes operated with the traffic signals, vehicles in the large network run on both sides and a few operational conditions and constraints unique to Manhattan style grid have been pre-defined as follows:

- Conditional Turning Movement

The ATIS model using V2V communication manages the number of possible routes from the specified origin to the destination by requiring all vehicles to avoid any cycles within their path and assumes there are no mid-path stops. Also, a vehicle will not select a movement (i.e., left, right or through) that results in increasing the Euclidian distance to the destination point. These path selection rules are utilized in DRGS as well and future efforts on more realistic networks will need to relax this constraint.

- Link Travel Time Measurements

Nine different possible travel times through two consecutive intersections may be identified by pairing turning activities conducted at the upstream and downstream intersections. However, this research tracks the travel time for only five different paths, following the aforementioned conditional turning movement rule (e.g., a vehicle would not turn left on to and then left off a link) and taking into account that travel time corresponding to a right turn at the downstream intersection would be similar to that of through movement, assuming no right-turn-on-red. For instance, 6X6 urban gird traffic network generates 720 link travel paths.

1. Basic Model Development

The basic framework of the proposed ATIS model using V2V communication consists of three key components: vehicle communication, on-board database management, and dynamic re-routing. The basic framework applied for the large traffic network in this paper has more capabilities to reflect the real-world implementation than that utilized by the small network experiments due to the aforementioned operational conditions and constraints. Following is the brief description of individual functions and impacts of them on the basic framework.

The communication model consists of two primary elements; communication group formation process and data dissemination process. The former process is accomplished via an algorithm developed to form communication groups composed of individual instrumented vehicles (i.e., participating vehicles hereafter) within single or multi-hop data communication range in the current communication time interval. After communication groups are formed, data may then be disseminated among vehicles within a group.

Travel time data is stored on each vehicle in an on-board travel time database in a 4-tuple (travel time, link number, vehicle ID, time bin). In the current implementation wall clock time is divided into three-minute intervals, referred to as system update time intervals, with the travel time of vehicle recorded during the three-minute bin that the vehicle exits the link. To make a routing decision each participating vehicle must estimate their expected travel time over their current route and all possible alternative routes. An on-board estimated link travel time update process is executed every system update time interval or instantly when traffic congestion messages are received. An estimated link travel time is the average of the travel time aggregated over the current time bin and the three previous bins.

This paper takes advantage of Dijkstra's algorithm (Rardin, 1997) to find the most time-efficient route from the current location to the final destination based on the estimated traffic state information every system update time interval or instantly as needed and designs the directed graphs to solve Dijkstra's algorithm.

Since participating vehicles running on the opposite direction could play an important role in disseminating the traffic data, wider formation of communication group and faster data propagation throughout the traffic network are possible compared to the small network experiments. Also, less traffic data might be available for traffic state update due to more separation of routes, implying more possibilities to rely on the historical data for the up-to-date traffic state updates, and much more variety of routes are available in searching for the optimal routes on the basis of the up-to-date traffic state information.

2. Advanced Model Development

The intended benefits of the developed basic framework may not be achieved due to delayed detection of non-recurrent traffic congestion, unreliable travel time estimates, and failure to account for driver sensitivity to time savings. Accordingly, this paper introduces and incorporates three more complementary functions (i.e., an Autonomous Automatic Incident Detection (AAID) algorithm, a dynamic sampling method, and driver's route choice rule) into the basic ATIS model using V2V communication to address these issues and improve the system efficiency and reliability (Kim *et al.*, 2009; Kim, 2011).

1) AAID Algorithm

Since participating vehicles update and disseminate the link travel time data when exiting a link in the basic ATIS model using V2V communication, other participating neighboring vehicles will not be able to update and remain unaware of a degraded downstream traffic state until a downstream participating vehicle successfully passes the incident area and communicates the link travel time of interest. On the other hand, the AAID algorithm implemented in the advanced ATIS model using V2V communication autonomously detects local non-recurrent traffic states by utilizing the elapsed time of a participating vehicle on a link. Each participating vehicle acts as an independent incident detection probe. If the elapsed time on a link ($P-E_j^i$) is sufficiently greater than a pre-defined time criterion (K) (e.g., 3 times longer than historical link travel time in this paper) the vehicle will issue and disseminate a congestion alert (UT) (Step 1) to neighboring vehicles. The congestion alert is given in the form of a travel time several orders of magnitude greater than the historic travel time. Vehicles receiving congestion information update their route instantly, not waiting for the next system update time interval. When a vehicle that issued a congestion alert departs its current link, the congestion alert is replaced with a message containing the actual travel time of the congested links ($E_{j+1}^i - E_j^i$) (Step 2).

Step 1: $T_{j,t,m}^i = UT, \qquad If\, P - E_j^i \geq K \times HT_{j,t}^i$

Step 2: $T_{j,t,m}^i = E_{j+1}^i - E_j^i\,, \quad If\, E_{j+1}^i > 0$

where:

P : current time
E_j^i : entering time of vehicle i on link j
K : user-defined congestion parameter (K factor)
$HT_{j,t}^i$: historical link travel time of vehicle i for link j and time bin t
UT : congestion alert link travel time

2) Minimum Sample Size

Traffic information systems collecting real time traffic data from probe vehicles should secure a sufficient number of probe vehicle data to reliably estimate travel time but the basic ATIS model using V2V communication estimates travel time with any sample size. However, the advanced ATIS model using V2V communication calculates the minimum sample size for individual links and time bin based on the archived historical travel time. Unlike the existing research effort conducted in the small traffic network (Kim, 2011), the normality test is conducted on the historical travel time for individual links with Shapiro-Wilk test (He *et al.*, 2002) and if null hypothesis that these data are from a normal distribution is not rejected, the minimum samples size is calculated with Eq. (1), otherwise, calculated using the heuristic method designed in this paper. Participating vehicles not meeting the required minimum sample size will use historical link travel times in calculating route travel times.

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

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's Route Choice Model

The real-time travel information provided from ATIS allows travelers 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 will depend to a large extent on understanding how drivers adjust their travel behavior in response to the information received (Dia and Panwai, 2007). The basic ATIS model using V2V communication, however, can trigger unnecessary re-routing with small differences in the travel time between routes without taking into account any travelers′ route selection behavior. On the other hand, this driver's route choice rule causes vehicles to disregard small differences in travel time between the current route and a slightly faster optimal route ($CTT^i - OTT^i$). This difference is referred to as an indifference band (I^i), which defines the percent improvement in travel time required before a vehicle will change routes (Mahmassani, 2001). This function leads to a more realistic driver behavior and limits participating vehicles from responding to potential short duration small variability in travel time calculations.

$$B^i = \begin{cases} 1, \text{ if } CTT^i - OTT^i > Max[I^i \times CTT^i, \tau_i] \\ 0, \ otherwise \end{cases}$$

where:

B^i : binary indicator equal to 1 if vehicle i changes its route, 0 otherwise;
CTT^i : current route travel time of vehicle i
OTT^i : optimal route travel time of vehicle i

I^i : user-defined relative indifference band of vehicle i with $I^i \geq 0$ (I factor)

τ_i : minimum improvement in the travel time required for vehicle i to change its route with $\tau_i \geq 0$

The capability of these three complementary functions also has been reinforced due to the grid network structure and more separation of travel time path compared to the small traffic network experiments. That is, grid network structure and separation of one link to five different travel time paths allow AAID algorithm to independently update local traffic states for the various directions throughout the traffic network, historical link travel times required to calculate the minimum sample size for one system update time interval become scarce, implying more dependence on the heuristic method to calculate the minimum sample size, and individual participating vehicles have more opportunities to detour the congested area.

Ⅳ. System Performance Evaluation

1. Experimental Design

Too simple traffic network might be insufficient to discuss the performance of the proposed ATIS model using V2V communication because its performance would be highly sensitive to both the network structure and size. Also, the network consisting of two-way links may facilitate the traffic data communication via other participating vehicles running on opposite direction links, thereby possibly resulting in mitigating the communication range impact. Therefore, this paper uses the 6X6 urban grid traffic network with an Eastbound traffic incident located in the center of the network, in effect from 1000sec to 2000sec with a vehicle release every 90sec to reflect vehicles slowly passing through the traffic incident area. Vehicles are generated at constant headways according to the desired traffic flow rate at desired speed 48kph. Each simulation experiment is run for 4800sec (i.e., 1200sec warm-up and 3600sec main runs) with the reported results from the average of ten replicates. Traffic signal timing parameters uniformly applied to all intersections are set to 2min cycle length, split phase (all through movements are assigned 41sec and left-turn vehicles 11sec effective green time, respectively), and 0sec 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 30sec. Average travel time savings of participating and (instant) re-routing vehicles are exploited as metrics to evaluate the system performance with respect to three underlying system parameters (i.e., traffic flow, communication radio range, and penetration ratio). 〈Table 1〉 shows the parameter values considered for individual system parameters.

All verification and evaluation processes of the proposed ATIS model using V2V communication have been conducted after the steady-state traffic condition is attained. Three traffic flow rates, 300vph, 514vph, and 720vph, at the constant vehicle input rate, 12sec, 7sec, and 5sec, respectively, have been tried and 300vph and 514vph have been selected as low and high traffic flow scenarios attaining the steady-state traffic condition around 1000sec with exclusion of 720vph scenario due to the over-capacity of the network. 250m of the communication radio range is consulted from the typical clear path range of an IEEE 802.11 communication system (Wu *et al.*, 2005), which

〈Table 1〉 System parameters and values for the experiment

Parameter	Value	Note
Traffic Flow	300vph (Low traffic flow)	Input headway = 12sec
	514vph (High traffic flow)	Input headway = 7sec
Communication radio range	250m (Short range)	Considering link distance = 382m
	375m (Intermediate range)	
	500m (Long range)	
Penetration Ratio	10%, 20%, 30%, 40%, 50%	Used for each combination of traffic flow and communication radio range

is typically available in the urban environments (Dubey *et al.*, 2011). Accounting for the link distance (i.e., 382m), 375m and 500m have been taken into account as the intermediate and long communication radio ranges as well. Lastly, Ng and Waller (2010) addressed from their numerical investigation of the data propagation speed in VANET that the low penetration ratio (〈 10%) is sufficient for the reasonable data dissemination speed in the initial deployment stages of V2V communication system and quite surprisingly more penetration ratio does not necessarily promote the fast dissemination of data. However, this paper ranges the penetration ratio from 10% to 50% with an assumption of full deployment of the system especially along the urban area and practical computational limitation of this paper such as significantly prolonged simulation running time due to exponentially increased communication activities among the participating vehicles at the higher penetration ratios.

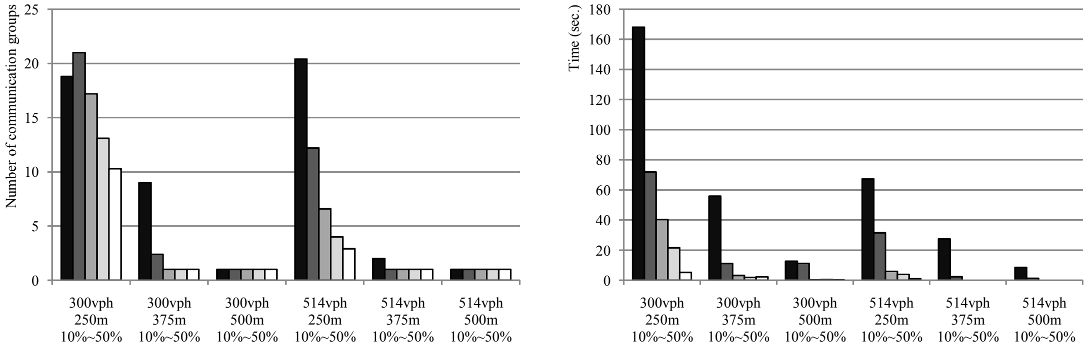
As stated before, this paper is the extended research efforts of (Kim, 2011) that investigated the system performance improvement of the advanced ATIS model using V2V communication compared to the basic model and conducted the sensitivity analysis of K and I factor values as well. He found that the advanced ATIS model using V2V communication coupled with AAID algorithm and driver's route choice rule is more constant, consistent, and robust in its performance (i.e., travel time savings) than the basic model. Additionally, the sensitivity analysis of K and I factors to the advanced model performance suggests the utilization of 2 or 3 and 20% or 30%, respectively. This paper selects more conservative value (i.e., probably issuing fewer false alarms) which is 3 (i.e., $P-E^i \geq 3\times HT^i_{j,t}$) among two possible values, K = 2 and 3 and uses I factor value already identified in (Chen and Mahmassani, 1991), 20%, between two potential values, I = 20% and 30%, that is, only when the travel time of an alternative route offers at least 20% travel time savings (i.e., $CTT^i - OTT^i > 0.2\times CTT^i$), participating vehicles are allowed to switch routes. Interestingly, all participating vehicles under the non-recurrent traffic state instantly perform their update process at the moment traffic congestion messages are received (i.e., (instant) re-routing vehicle), not at the scheduled interval.

Furthermore, the long-term simulation run under normal traffic condition finds that most normality test results of travel time distribution for each link rejected the null hypothesis (i.e., the travel time data is normally distributed) resulted from the significant travel time variability due to the traffic signal effect. Therefore, the developed heuristic method for the reliable sample size calculation has been utilized, but some links requires 80% of the average maximum number of vehicles, implying that unless the penetration ratio of the participating vehicles approaches 80%, the system relies on the historical link travel time, not real-time actual traffic information, for the route update, resulting in the ATIS system essentially ignoring the participating vehicle data under nearly all scenarios tested. Clearly, given the variability of traffic flow under signalized conditions the proposed minimum sample size is too conservative, requiring significantly more data than practical or often possible and highlighting a need to revisit the minimum sample size issue and the trade-off between reliable data and ignoring potentially meaningful information. This paper is subsequently employing a minimum sample size 2 for each link to investigate the performance of the various ATIS models using V2V communication on signalized networks (Kim, 2010).

2. Validation of V2V Communication System

Prior to evaluation of the advanced ATIS model using V2V communication, the behavior of V2V communication system has been validated so as to ensure that difference of the simulation output results from the varying system parameters. 〈Figure 1〉 depicts that high flow rate, wider radio range, and high penetration ratio have fewer communication groups and more participating vehicles per communication group at the faster data dissemination speed. Interestingly, the number of communication groups in (300, 250, 10) case ((flow rate, communication radio range, penetration ratio) represents a specific case hereafter) is smaller than that of (300, 250, 20) case because the traffic flow, radio range, and penetration ratio in the former case are limited for communication group formation. On the other hand, from (300, 250, 20) case the communication group formation patterns show the intuitive effect of the three key system parameters (〈Figure 1(a)〉).

While communication group numbers seem to be dominated by the penetration ratio at the short radio range (250m), the intermediate radio range (375m) is long enough to generate one communication group containing all participating vehicles available in the network, excluding a few low penetration ratio cases like (300, 375, 10), (300, 375, 20) and (514, 375, 10) (〈Figure 1(a)〉). Taking the link distance (382m) into account, this result seems very reasonable. For instance, as the number of communication groups decrease, the average number of participating vehicles in one communication group increases. Therefore, an update of link travel time can be disseminated



(a) Average number of communication groups

(b) Data dissemination speed

〈Figure 1〉 Vehicle communication validation process simultaneously to all participating vehicles in the network (〈Figure 1(a)〉).

〈Figure 1(b)〉 shows the elapsed time required for the travel time of the bottom left vertical or horizontal link to reach the center of the network through multi-hop communications for the validation of data dissemination process after the steady-state traffic condition is attained. It reveals that more communication-favorable cases (i.e., high flow rate, wider radio range, and higher penetration ratio) facilitate fast data dissemination with the short elapsed time. The derived simulation outputs for the system validation are well matched with the existing research efforts on the evaluation of data dissemination speed with respect to the varying traffic flows and penetration ratios, using the integrated simulation model and analytical method (Wu *et al.*, 2005; Ziliaskopoulos and Zhang, 2002).

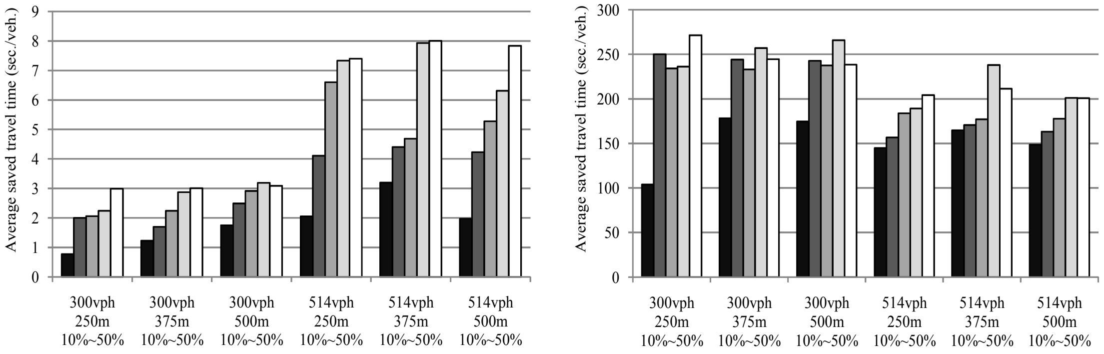
3. Travel Time Savings Comparison

The advanced ATIS model using V2V communication is evaluated with respect to the average travel time savings of participating vehicles as well as (instant) re-routing participating vehicles, followed by the temporal and spatial analysis of vehicle re-routing patterns. 〈Figure 2(a)〉 indicates that higher flow rates and penetration ratios result in a higher average travel time savings for participating vehicles. Travel time savings are generated from the traffic incident-involved re-routing of participating vehicles. This metric is directly related to the traffic demand and number of existing participating vehicles, but less to the communication radio range as one system update time interval is a sufficiently long time that any participating vehicles can pass at least one link and share that travel time network-wide neighboring vehicles due to repeated and frequent establishment and breaking of communication links.

Focusing on (instant) re-routing vehicles contributing to travel time savings, 〈Figure 2(b)〉 shows that even though number of (instant) re-routing vehicles in 300vph case might be less than that of 514vph case the former case seems to save more time per (instant) re-routing vehicle than the latter case. The following investigation addresses this issue using the (300, 500, 30 / 40 / 50) and (514, 500, 30 / 40 / 50) cases by way of example.

4. Temporal and Spatial Analysis

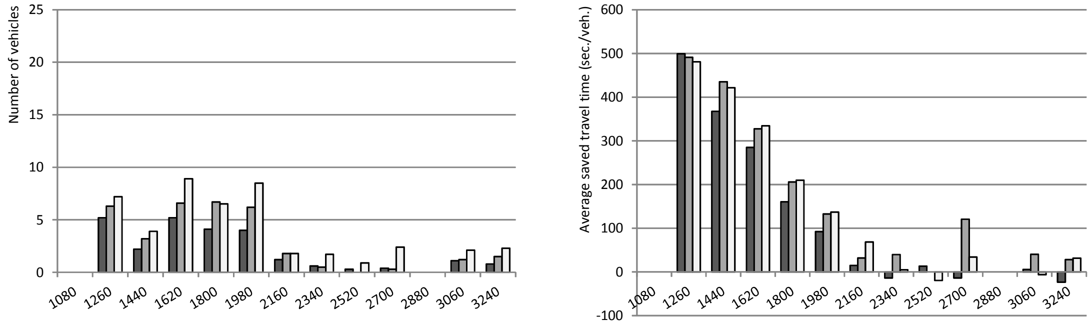
While the small traffic network experiments



(a) Participating vehicles (b) (Instant) re-routing vehicles

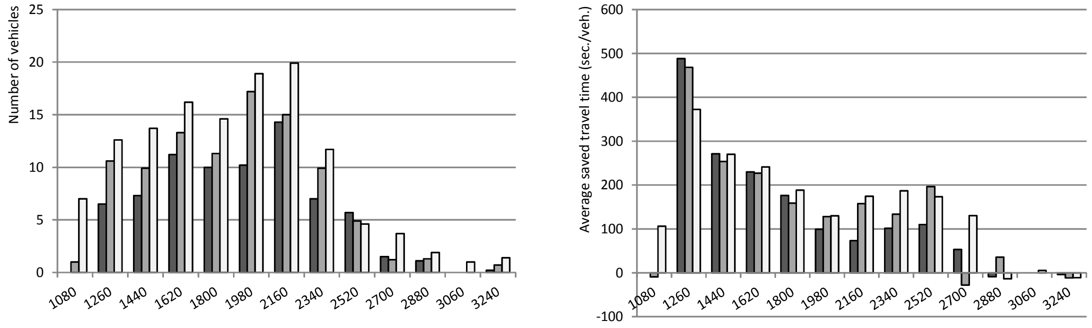
〈Figure 2〉 Average travel time savings comparison investigated the system performance at the aggregated level by varying eight different types of ATIS model (Kim, 2011) with the intrinsic drawbacks of the traffic network size and structure, this paper examines the more comprehensive ATIS model at temporally and spatially disaggregated level in the larger traffic network.

〈Figure 3〉 depicts the temporal pattern of vehicle re-routing and average travel time savings after the incident occurs at 1000sec. The 500m radio range case at penetration ratios of 30%, 40%, and 50% is selected for comparison. 〈Figure 3〉 confirms that travel time savings are greater for vehicles that re-route relatively soon after the incident and that the number of re-routing vehicles is relatively densely distributed between 1200sec to 2500sec as a result of traffic congestion messages during the effective traffic incident time period (i.e., from 1000sec to 2000sec). Vehicle re-routing effect on the system performance with the low traffic flow case (〈Figure 3(b)〉) is almost negligible from 2160sec because the traffic state quickly returns to the normal traffic condition after the traffic incident is resolved. For the high flow rate case a significant portion of re-routing vehicles after the traffic incident is resolved are triggered by traffic congestion messages issued on other links adjacent to the incident link as an aftermath of the traffic incident and by previous traffic congestion messages that have not yet expired (i.e., less system-efficient time period) (〈Figure



(a) Number of re-routing vehicles
(300, 500, 30 / 40 / 50) case

(b) Average travel time savings
(300, 500, 30 / 40 / 50) case



(c) Number of re-routing vehicles
(514, 500, 30 / 40 / 50) case

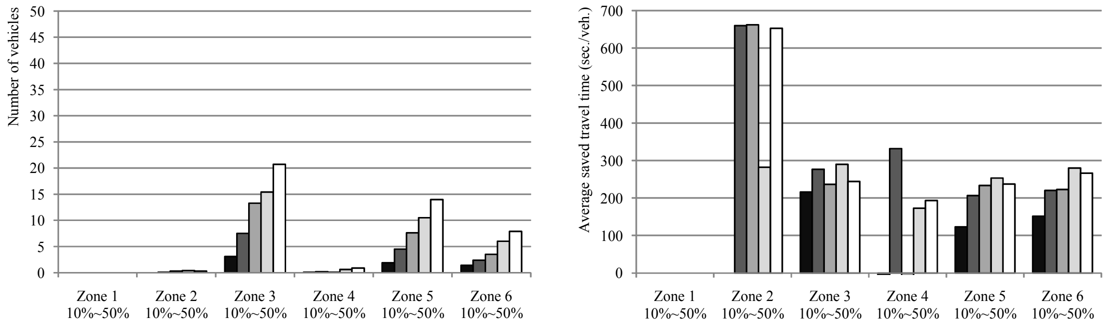
(d) Average travel time savings
(514, 500, 30 / 40 / 50) case

〈Figure 3〉 Temporal analysis of vehicle re-routing and average travel time savings

Note: X-axis indicates the simulation time and each group of bar graphs is composed of 3 penetration ratios from 10% to 30% in 10% increment.

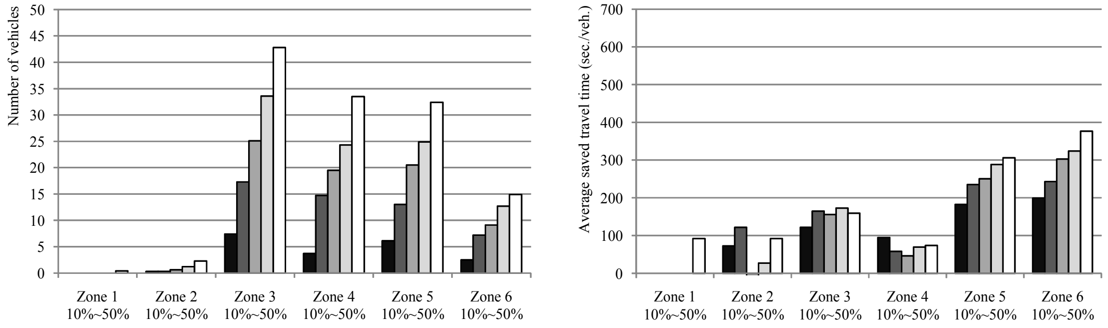
3(d)〉). The travel time saving of these incidents is lower than that of vehicles re-routed around the primary incident. Consequently, the average travel time savings of re-routed vehicles in the higher flow case is lower.

This paper also performed a spatial analysis of re-routing vehicles to investigate the spatial relationship between the traffic incident location and vehicle re-routing location and travel time savings with the varying penetration ratio. 〈Figure 4〉 shows the spatial characteristics of re-routing vehicles in 500m radio range case for two traffic flow rate cases. Zones in 〈Figure 4〉 indicate some part of the network including a group of links in the same distance (i.e., same number of links) from the incident link. For instance, Zone 3 means a group of links apart from the incident link by three links. If the location at which vehicles initially choose to re-route was uniformly distributed over the network links in Zones 3 or 4 would be expected to contain more re-routing vehicles due to their larger area. However, Zone 4 has a very small number of re-routing vehicles in the 300vph case (〈Figure 4(a)〉) and the travel time saving pattern is also irregular (〈Figure 4(b)〉). However, Zones 3, 4 and 5 have the most re-routing vehicles in 514vph case (〈Figure 4(c)〉) and Zones 5 and 6 saved more time from the traffic incident because the outer and network-entering zones have more opportunities to choose less incident-involved routes than the inner zones. Also, while the significant travel time saving of vehicles re-routing in the Zone 2 in 300vph case (〈Figure 4(b)〉) is interpreted as small number of vehicle re-routings that occurred in the beginning time period of the traffic incident and due to the direct congestion



(a) Number of re-routing vehicles (300vph)

(b) Average travel time savings (300vph)



(c) Number of re-routing vehicles (514vph)

(d) Average travel time savings (514vph)

〈Figure 4〉 Spatial analysis of vehicle re-routing and average travel time savings effect of the incident, much less time savings of re-routing vehicles in the Zone 2 in 514vph case (〈Figure 4(d)〉) is because they re-routed in the less system-efficient time period and with the indirect incident effect.

Ⅴ. Conclusions

This paper attempts to build and test an ATIS model that can model communication characteristics in urban areas using a widely accepted off-the-shelf transportation microscopic simulation model, rather than employing existing mobility models used in communication network simulators, by incorporating basic features of wireless vehicle communication under an ideal communication environment into the microscopic traffic simulator. The ATIS model using V2V communication consists of three basic system modules (vehicle communication, on-board database management, and DRGS) and its performance has been further enhanced by three complementary functions (AAID algorithm, minimum sample size, and driver's route choice rule). The significant distinction between this paper and other relevant research on the application of V2V communication system is to develop a comprehensive ATIS model, implementing the aforementioned modules and functions, not to pursue a partial ATIS model. Thus, this paper contributes to ITS knowledge as preceding studies tended to be more focused on specific research topics opposed to comprehensive system development. In addition, unlike the small traffic network employed in the existing research efforts (Kim *et al.*, 2009; Kim 2011) with limited number of by-path routes and one-way links, this paper investigated the characteristics of the proposed ATIS model using V2V communication and evaluated its performance with an off-the-shelf microscopic simulation model in the typical Manhattan style urban grid network under the traffic incident situation.

Prior to the system evaluation, the validation process of vehicle communication module found that as traffic demand, radio range, and penetration ratio increase, the number of communication groups decreases and traffic data is disseminated faster. Also, the ATIS model using V2V communication performance has been evaluated with respect to the travel time savings. Participating vehicles saved more time at the higher flow rate and penetration ratio. The radio range was not an important factor affecting the system performance because the radio range restriction has been easily overcome by fast mobility and multi-hop communication of participating vehicles.

Focusing on the travel time difference of (instant) re-routing vehicles, lower traffic flow cases saved more time than higher traffic flow on average because in the lower demand case fewer vehicle 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. Most re-routing decisions occurred on the network-entering links and the location and direction of the incident link determines the spatial distribution of re-routing vehicles.

These findings indicate that such an ATIS model using V2V communication appears feasible. However, future research is required to better explore potential communication issues, such as message delay or drops, message contention, dissemination methods, variability in communications range, urban canyon effects, etc. In addition, it is important to note that estimated travel times do not incorporate the possible re-routing of other participating vehicles based on received data. That is, the estimates are based on the traffic flow currently in the system, should a significant subset of participating vehicles change their route in response to this data than significant differences may be witnessed between the estimated travel times and travel times in the near future. As participating vehicles use the estimated travel time as the near future travel time prediction for routing decisions this behavior can significantly impact the quality of the system performance. This behavior is a well recognized challenge in the dynamic traffic assignment (DTA) literature (Ben-Akiva 1991). Furthermore, since most underlying system parameters are defined by the characteristics of used traffic network, more various and realistic traffic network have to be implemented with more traffic control methods (i.e., actuated or semi-actuated traffic signal controls) and the effect of the different incident location and its severity (i.e., incident duration) should be investigated as well.

Consequently, the proposed ATIS model using V2V communication, updating the local state information because of the possibly limited communication capability, might be less accurate than the fixed infrastructure-based ATIS model, resulting in that the two types of model would have slightly different vehicle re-routing patterns and traffic incident identification. In spite of the potentially less accurate output of the ATIS model using V2V communication the possible non-trivial time lags in the fixed infrastructure-based ATIS model between the occurrence of the non-recurrent traffic state and provision of the responsive new route (Hawas and Mahmassani, 1996; Chiu and Mahmassani, 2002, 2003) due to intensive computational resources to constantly trace time and location of all participating vehicles and heavy predictive input information for the large network can be overcome by the ATIS model using V2V communication. Also, some delay of the update of traffic congestion messages in the ATIS model using V2V communication due to the communication restriction, particularly at low traffic flow, smaller radio range, and low penetration ratio might not cause significant system performance discrepancy from the fixed infrastructure-based ATIS model output due to the high mobility and multi-hop data dissemination method with the participating vehicles. Hence, the decentralized ATIS model using V2V communication system might be a reasonable alternative to the fixed infrastructure-based ATIS model.

References

1. 김형수·신민호·남범석·David J. Lovell (2008), "애드혹 네트워크 기반 교통 시스템을 위한 컴퓨터 모의실험 환경 설계", 대한교통학회지, 제26권 제6호, 대한교통학회, pp.93~101.
2. 김회경 (2011), "Development and evaluation of Advanced Framework of ATIS model", 교통연구, 제18권 제1호, 한국교통연구원, pp.75~88.
3. Ben-Akiva, M., A. Palma, and I. Kaysi (1991), "Dynamic network models and driver information systems", Transportation Research Part A, Vol. 25, No. 5, pp.251~266.
4. Ben-Akiva, M., M. J. Bergman, A. J. Daly, and R. Ramaswamy (1984), "Modeling inter urban route choice behavior", Proceedings of 9th International Symposium on Transportation and Traffic Theory, VNU Science Press, pp.299~330.
5. Chen, P. S. and H. S. Mahmassani (1991), "Reliability of real-time information systems for route choice decisions in a congested traffic network: some simulation experiments", Proceedings of IEEE Conference on Navigation and Information Systems, IEEE, pp.

849~856.
6. Chiu, Y. C. and H. S. Mahmassani (2002), "Hybrid real-time dynamic traffic assignment approach for robust network performance", Transportation Research Record: Journal of the Transportation Research Board, No. 1783, Transportation Research Board of the National Academies, Washington, D.C., pp.89~97.
7. Chiu, Y. C. and H. S. Mahmassani (2003), "Routing profile updating strategies for online hybrid dynamic traffic assignment operation", Transportation Research Record: Journal of the Transportation Research Board, No. 1857, Transportation Research Board of the National Academies, Washington, D.C., pp.39~47.
8. Dubey, B. B., N. Chauhan and S. Pant (2011), "Effect of position of fixed infrastructure on data dissemination in VANETs", International Journal of Research and Reviews in Computer Science (IJRRCS), Vol. 2, No. 2, pp.482~486.
9. Dia, H. and S. Panwai (2007), "Modelling drivers' compliance and route choice behaviour in response to travel information", Journal of Nonlinear Dynamics, Vol. 49, No. 4, pp.493~509.
10. Eichler, S., B. Ostermaier, C. Schroth, and T. Kosch (2005), "Simulation of car-to-car messaging: analyzing the impact on road traffic", Proceedings of 13th International Symposium on Modeling, Analysis, and Simulation of Computer and Telecommunication, IEEE, pp.507~510.
11. Guin, A. (2004), "An Incident Detection Algorithm Based on a Discrete State Propagation Model of Traffic Flow", Ph.D. Dissertation in Civil Engineering, Georgia Institute of Technology.
12. Hawas, Y. E. and H. S. Mahmassani (1996), "Comparative analysis of robustness of centralized and distributed network route control systems in incident situations", Transportation Research Record: Journal of the Transportation Research Board, No. 1537, Transportation Research Board of the National Academies, Washington, D.C., pp.83~90.
13. He, R. R., H. X. Liu, A. L. Kornhauser, and B. Ran (2002), "Temporal and Spatial Variability of Travel Time", Center for Traffic Simulation Studies, University of California at Irvine.
14. Hormann, Y., H. P. Grossmann, W. H. Khalifa, M. Salah, and O. H. Karam (2004), "Simulator for inter-vehicle communication based on traffic modeling", Proceedings of Intelligent Vehicles Symposium, IEEE, pp.99~104.
15. Hui, F. and P. Mohapatra (2005), "Experimental characterization of multi-hop communications in vehicular ad hoc network", Proceedings of the 2nd ACM International Workshop on Vehicular ad hoc Networks, Association for Computing Machinery, pp.85~86.
16. Krajzewicz, D., D. T. Boyom, and P. Wagner (2008), "Evaluation of the performance of citywide, autonomous route choice based on vehicle-to-vehicle communication", Proceedings of 87th TRB Annual Meeting, TRB.
17. Kim, H. (2007), "A Simulation Framework for Traffic Information Dissemination in Ubiquitous Vehicular Ad Hoc Networks", Ph.D. Dissertation in Civil and Environmental Engineering, University of Maryland.
18. Kim, H. K., M. P. Hunter, and R. M. Fujimoto (2009), "A simulation-based investigation of a dynamic advanced traveler information system", Proceedings of 2009 Winter Simulation Conference, WSC, Austin, TX.

19. Kim, H. K. (2010), "Development and Evaluation of Advanced Traveler Information System (ATIS) Using Vehicle-to-Vehicle (V2V) Communications System", Ph.D. Dissertation in Civil Engineering, Georgia Institute of Technology.
20. Krajzewicz, D., D. T. Boyom, and P. Wagner (2008), "Evaluation of the performance of city-wide, autonomous route choice based on vehicle-to-vehicle-communication", Proceedings of 87th Annual Meeting of the Transportation Research Board, Washington, D.C.
21. Mahmassani, H. S. (2001), "Dynamic network traffic assignment and simulation methodology for advanced system management applications", Networks and Spatial Economics, Vol. 1, No. 3, pp.267~292.
22. Michael, L. B. and M. Nakagawa (1996), "Multi-hop for inter-vehicle communication over multiple lanes", Proceedings of Intelligent Vehicles Symposium, IEEE, pp.284~288.
23. Ng, M. and S. T. Waller (2010), "A static network level model for the information propagation in vehicular ad hoc networks", Transportation Research Part C: Emerging Technologies, Vol. 18, No. 3, pp.393~407.
24. Petty, K., P. J. Bickel, J. Kwon, M. Ostland, and J. Rice(2002), "A new methodology for evaluating incident detection algorithms", Transportation Research Part C: Emerging Technologies, Vol. 10, No. 3, pp.189~204.
25. PTV. (2009)a, "VISSIM 5.10 User Manual", Planung Transport Verkehr (PTV) AG, Karlsruhe, Germany.
26. PTV. (2009)b, "VISSIM 5.10 COM Interface Manual", Planung Transport Verkehr (PTV) AG, Karlsruhe, Germany.
27. Rardin, R. (1997), "Optimization in Operations Research", Prentice Hall, Upper Saddle River, New Jersey.
28. Srinivasan, K. K. and P. P. Jovanis (1996), "Determination of number of probe vehicles required for reliable travel time measurement in urban network", Transportation Research Record: Journal of Transportation Research Board, No. 1537, Transportation Research Board of the National Academies, Washington, D.C., pp.15~22.
29. Wischhof, L., A. Ebner, and H. Rohling (2005), "Information dissemination in self-organizing inter-vehicle networks", IEEE Transactions on Intelligent Transportation Systems, Vol. 6, No. 1, IEEE, pp.90~101.
30. Wu, H., R. Fujimoto, and G. Riley (2004), "Analytical models for information propagation in vehicle-to-vehicle networks", Proceedings of the 60th Vehicular Technology Conference, IEEE, pp.4548~4552.
31. Wu, H., J. Lee, M. Hunter, R. Fujimoto, R. L. Guensler, and J. Ko (2005), "Efficiency of simulated vehicle-to-vehicle message propagation in Atlanta, Georgia, I-75 Corridor", Transportation Research Record, Vol. 1910, pp.82~89.
32. Xu, H. and M. Barth (2004), "A transmission-interval and power-level modulation methodology for optimizing inter-vehicle communications", Proceedings of 1st International Conference on Mobile Computing and Networking, Philadelphia, PA, pp.97~98.
33. Xu, H. and M. Barth (2006), "Travel time estimation techniques for traffic information systems based on inter-vehicle communications", Transportation Research Record: Journal of Transportation Research Board, No. 1944, Transportation Research Board of the National Academies, Washington, D.C., pp.72~81.

34. Yang, X. (2003), "Assessment of A Self-Organizing Distributed Traffic Information System: Modeling and Simulation", Ph.D. Dissertation in Civil Engineering Department, University of California at Irvine.

35. Ziliaskopoulos, A. K. and J. Zhang (2002), "A zero public infrastructure vehicle based traffic information system", Proceedings of 81st Annual Meeting of the Transportation Research Board, Washington, D.C.

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