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A SIMULATION-BASED INVESTIGATION OF A DYNAMIC ADVANCED TRAVELER INFORMATION SYSTEM

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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 investigates a basic ITS framework - Advanced Traveler Information System (ATIS) - using wireless vehicle-to-vehicle and vehicle-to-roadside communication and assuming an ideal communication environment. Utilizing an off-the-shelf microscopic simulation model this paper explores both a centralized (CA) and decentralized (DCA) ATIS architecture. 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. Challenges are also noted in relying solely on instrumented vehicle data in an ATIS implementation.

1 INTRODUCTION

According to the Urban Mobility Report developed by the Texas Transportation Institute in 2007 (Schrank and Lomax 2007), 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 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. 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-Center communication (V2C) and Vehicle-to-Vehicle communication (V2V). Enabled by wireless communication with the surrounding infrastructure or neighboring instrumented vehicles each participating vehicle in such an ATIS may act as a real time traffic data collector (e.g., link travel time in this paper), a traffic information provider, and a traffic information consumer.

The Dynamic Route Guidance System (DRGS) is an effective and practical ATIS application that uses wireless communication. DRGS attempts to search for the most cost effect route (typically measured in terms of travel time) from the origin to the destination for a participating vehicle. DRGSs are commonly defined as decentralized or centralized. According to the U.S DOT National ITS architecture a DRGS is decentralized when the instrumented vehicle is given traffic data from the information service provider (ISP) and it determines its own preferable route. The centralized DRGS not only collects and fuses real-time ITS data but also finds and disseminates the predictive optimal route to participating vehicles (U.S. DOT 2007). An example of a centralized DRGS is the ADVANCE project conducted in Chicago in the early to mid 1990s. The ISP of the ADVANCE project (Sen, Soot, Thakuriah, and Condie 1996) collected traffic information from multiple data sources including probe vehicles and disseminated user-optimal route information to the drivers. Other centralized DRGS examples included two simulation-based Dynamic Traffic Assignment (DTA) systems, i.e., DynaMIT and DynaSmart (Ben-Akiva, Bierlaire, Koutsopoulos, and Mishalani 1998, Maryland Transportation Initiative 2003, Smith 1996). These software packages are capable of estimating and predicting the traffic state based on various on-line traffic data and determining optimal routes (i.e., user equilibrium or system optimal) consistent with future traffic states by using internal driver behavior models. In this study we propose two centralized systems, instantaneous prescriptive and predictive prescriptive route calculation algorithms (Schmitt and Jula 2006, Herbert and Mili 2008). We also propose a decentralized system. In our decentralized system participating vehicles utilize their own traffic data as well as that received from neighboring participating vehicles. Using this data participating vehicles autonomously find their own optimal routes. In our decentralized model traffic data is collected by, processed, and stored on the vehicles. The transfer of traffic data is facilitated by the wireless transmission between vehicles and the movement of the vehicles themselves (Wu, Fujimoto, Riley, and Hunter 2009). This is an alternative decentralized approach than those where vehicles interact with fixed roadside servers distributed throughout the system that receive, process data, and handle predictive functions. (Ando, Masutani, Sasaki, Iwasaki, Fukazawa, and Honiden 2006).

Prior to the introduction of traffic information systems using wireless communication the transportation and communication fields were generally treated as independent research areas. However, the synergetic integration of these two different fields may potentially result in the implementation of a traffic information system using wireless communication with vehicles acting as active participants in data collection and analysis. A number of researchers have investigated the federation of traffic mobility simulators and communication simulators (Eichler, Benedikt, Schroth, and Kosch 2005, Laborczi, Torok, Vajda, Kardos, Gordos, and Gerhath 2006, Wu, Fujimoto, Riley, and Hunter 2009). However, these efforts have typically attempted to bring together disparate simulation and communication models.

This paper aims to propose a potential architecture of dynamic ATIS by directly integrating the communication model, ITS database management process, and dynamic routing process into a vehicle simulation, develop and evaluate the proposed model, and investigate its basic characteristics. An off-the-shelf microscopic simulation model (i.e., VISSIM and VISSIM COM) is utilized with a simplified dynamic ATIS architecture using wireless communication integrated into the transportation simulation framework. The ATIS performance is investigated on a simple notional traffic network in an attempt to explore the feasibility of the integration of such an ATIS architecture in a commercial simulation and understand the basic operational characteristics of the approach. Future investigations will provide more in depth analysis, exploring the different facets of the architecture on a larger traffic network. This paper is organized as follows: section 2 describes the developed ATIS model, the experimental design is presented in section 3 and the results in section 4. Lastly, section 5 provides a brief summary.

2 SYSTEM DEVELOPMENT AND OPERATION METHODOLOGY

Both centralized ATIS (CA) and decentralized ATIS (DCA) models are proposed. The CA model is assumed to utilize a centralized traffic information center while the decentralized system depends solely on data (i.e., travel times) shared between vehicles. Two different methods (CA1 and CA2) are investigated for updating the centralized ATIS database and one method for updating the decentralized ATIS into on-board databases. Section 2.1 presents an overview of the communications architecture for the CA and DCS methods, section 2.2 discusses the database update schemes, and finally section 2.3 presents the application of the updated routing information.

2.1 Communication

The Vehicle Communication Module (VCM) contains the Vehicle-to-Vehicle (V2V), Vehicle-to-Roadside (V2R), and Vehicle-to-Center (V2C) communication logic. For this effort a simplified model is developed assuming an idealized communication environment. A separate communication architecture is utilized for each CA and DCA model, as described below. Future efforts will improve the VCM, incorporating communication-related parameter values configured for a specific region.

2.1.1 Centralized ATIS (CA)

The CA models exploit wireless communication between roadside communication units and participating vehicles (Tomkewitsch 1991). For the CA models it is assumed that the entire traffic network is within the communication range of the roadside units and the traffic information center. Traffic data is sent from participating vehicles to the traffic information center on a periodic basis to update the central database and route calculations algorithm. The length of the update interval is a user specified parameter. Here, a 1 second update interval is utilized. The impact of the length of this time period is under investigation.

2.1.2 Decentralized ATIS Model (DCA Model)

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. Instantaneous data exchange is assumed through multi-hop communication within these groups. 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 (Dhoutaut and Lassous 2004, Enkelmann 2003, Wu, Lee, Hunter, Fujimoto, Guensler, and Ko 2005). In the current implementation it is also assumed that the radio range is not affected by any obstacles and that data is not lost during communication.

2.2 Travel Time Database Update

The efficient management of the spatial and temporal travel time information is a core element of an ATIS DRGS system. In this DRGS implementation travel time information is stored in a module called the space-time memory residing in the traffic information center (CA models) or on-board each participating vehicle (DCA model). As the participating vehicle is traversing the network it saves its travel time data to its local space-time memory, communicating updates with roadside units or neighboring participating vehicles each update interval. Using the travel time data gathered each update interval the central database (CA models) or on-board databases (DCA model) are updated, allowing for the calculation of revised routing information.

2.2.1 Database Update - CA1 (Centralized Instantaneous ATIS)

The centralized instantaneous ATIS (CA1) is depicted in Figure 1. In the database representation shown in Figure 1 each column represents a link and the letters represent the link travel time for the current update interval. At the start of a CA1 model run the space-time memory is seeded with historical travel times (Step 1). Each time interval the CA1 central database receives traffic state information from participating vehicles that completed the traversal of a link since the previous update. For instance, in Step 2 of the CA1 update (Figure 1, left side): two vehicles complete a traversal of link 1 in the latest update interval, one of link 2, one of link 3, none of link 4, and so on. The model aggregates the new link data and updates the link travel time in the database (Steps 3). Links where no new travel time data is obtained continue to use the previous (i.e. last recorded) travel time (Step 3 and Step 6).

2.2.2 Database Update – CA2 (Centralized Predictive ATIS)

Unlike the instantaneous update method of the CA model, the predictive update method provides some smoothing of the travel time data using a moving average approach. A depiction of the CA2 method is seen on the right side of Figure 1. In this implementation time is divided into bins, starting at time zero and continuing throughout the experiment. At any time *t* 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. For this effort three minute bins are utilized. As seen in Figure 1 when the CA2 ATIS model is initialized, the centralized travel time database is seeded with historical link travel times (Step 1). In Steps 2 and 3 estimated link travel times at any time *t* are computed as follows:

$$LTT_j = \sum_{T(\#)=T(C-3)}^{T(C)} \sum_{i=1}^{n_j^{T(\#)}} \frac{VTT^i_{j,T(\#)}}{n_j^{T(\#)}}$$

where: LTT_j = Estimated travel time for link *j* at time *t*.

T(#) = Travel time bin number #, where bins are numbered consecutively from the start of simulation. *C* represents the bin number for the current simulation time.

$VTT^i_{j,T(\#)}$ = Travel time for Vehicle *i* to traverse link *j* during time bin *T(#)*.

$n_j^{T(\#)}$= The number of participating vehicles that complete their traversal of link *j* during time bin *T(#)*.

For example, cell (L1,T1) is the average of travel times for vehicles that complete their traversal of link L1 during time period T1 (i.e. from 0 seconds to 180 seconds), cell (L1,T2) is the average of travel times for vehicles that complete their traversal of link L1 during time period T2 (i.e. 181 seconds to 360 seconds), and so on. The L1 estimated travel time at time *t* = 700 is then the average of cells (L1,T1), (L2,T2), (L3,T3) and (L4,T4). Where no vehicles complete a traversal of a link during a time bin the bin travel time for that link is taken as the historical travel time (Step 6). For this effort the number of time bins and bin length utilized to estimate and predict link travel times are selected based on experienced gained in initial model development. However, it is readily recognized that these assumptions can significantly influence the ATIS performance and thus should be further studied in future analysis. It is anticipated that no single set of bin parameters (i.e. number utilized and length) will be found to hold, with the best parameters likely of function of the given network size and structure and the desired robustness of the travel time estimates. In this effort four time bins, 180 seconds per bin, are utilized for travel time estimation and prediction.

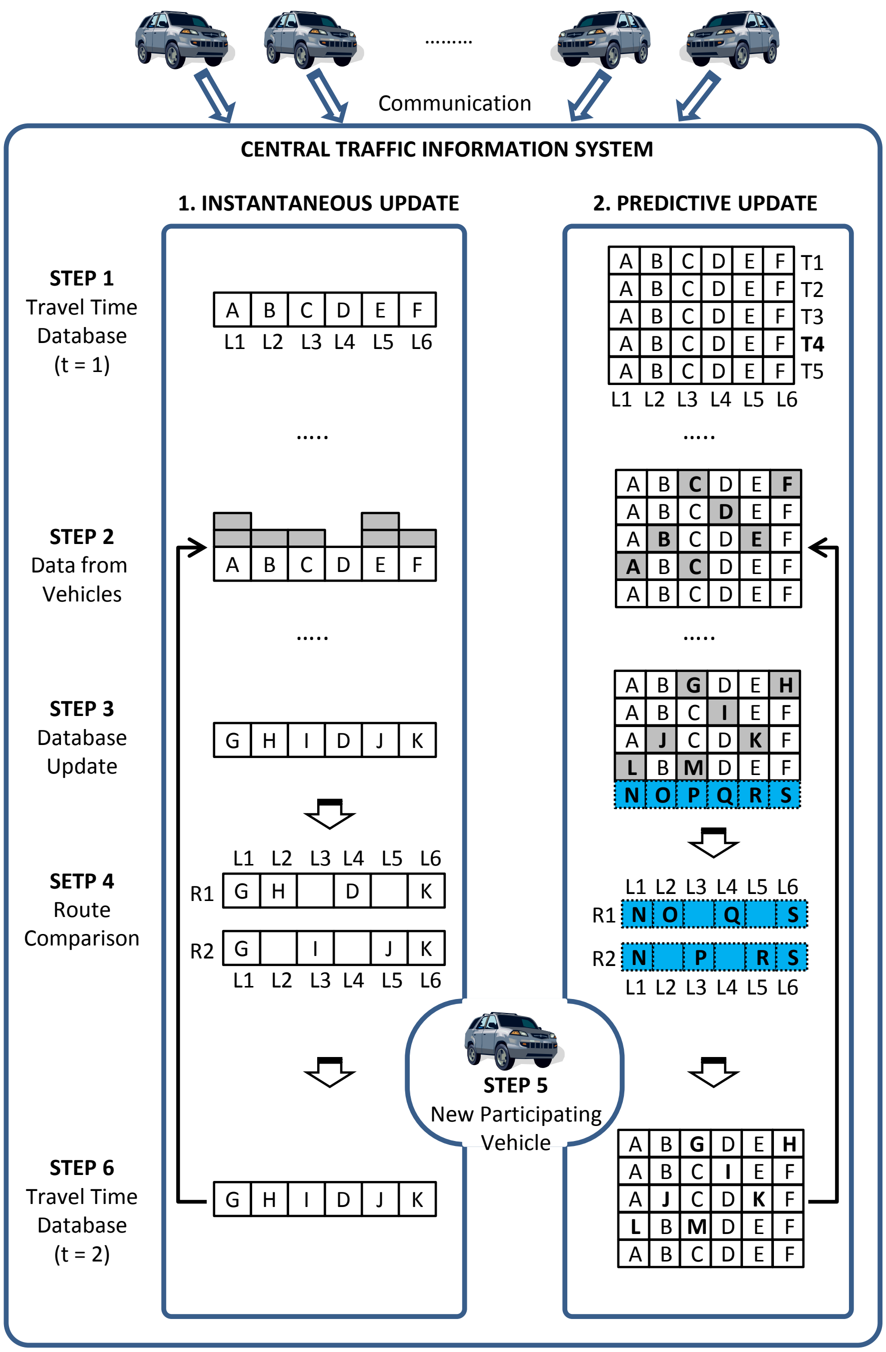


Figure 1: Concept of traffic database update method in the CA model

Note: Alphabet in the white cell = historical link travel time / Alphabet in the gray cell = updated link travel time

L# = link number / R# = route number / T(#) = time bin

2.2.3 Database Update - DCA (Decentralized ATIS)

The database update method in the DCA model is similar to that of the CA2 model. The primary difference is that each vehicle autonomously executes database updates and route selection on-board the vehicle, utilizing received data. Thus, in the CA2 model the central database is assumed to receive data from all vehicles in the network while in the DCA model a vehicle will only have that data that has been received through the V2V data communication between participating vehicles. In the current implementation the data passed between vehicles is the individual travel time data. That is, a vehicle will pass to another participating vehicle its own travel time data and that data it has received from other participating vehicles. Participating vehicles do not pass any aggregate travel time values. Individual vehicle link travel times are also identified with the subject vehicle ID and a times stamp such that a receiving vehicle may identify when it receives duplicate link travel time data from multiple sources. It is noted that for any given time bin some links may be updated with new information while others rely on historical data.

2.3 Route Updates

In the current implementation the CA and DCA models apply different route update schemes. In the CA model at each update interval the travel time is calculated for each route in the network based on the current centralized link travel time database (Figure 1, Step 4). As each new vehicle enters the network its route is selected based on the current route travel times (Step 5). A vehicle currently in the network is not sent an updated route based on updates that may occur in the centralized database during that vehicle's trip. Essentially, this is the equivalent of travelers checking the traffic conditions at the start of their trip and using that information to make their route selection (e.g., picking your route to work based on the reported traffic conditions when you leave your house). It is assumed that after beginning their trip the travelers receive no new traffic reports that might cause them to change routes.

Route update process in the DCA model is different from that of CA model in that the travel time databases reside on the vehicles themselves and at the end of each time bin (3 minutes in the current implementation) each participating vehicle will recalculate the optimal route from its current position to its final destination (Step 4). If this route is different from the vehicle's current route the vehicle will change routes (Step 5). This is the equivalent to a traveler selecting their initial route to work but receiving new information during their trip (e.g., from a radio traffic report) and changing their route based on that data. 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 (Mahmassani and Chen 1991). In this experiment we utilize a 10-second time threshold. It is recognized that the appropriate value for such a threshold will likely be highly dependent on the configuration of the network under consideration, however, this issue is reserved for future study and not covered within this paper.

2.4 Microscopic Simulation Model (VISSIM and VISSIM COM)

To conduct a realistic test of the wireless communication ATIS model described it is necessary to simulate traffic at the individual vehicle level, so an off-the-shelf microscopic simulation model, VISSIM 5.10, is utilized to leverage established and verified vehicle movement models. VISSIM, a German acronym for "Verkehr In Staedten SIMulation (traffic in towns – simulation)", is a microscopic, stochastic, time step and behavior based simulation model developed at the University of Karlsruhe, Germany, in the early 1970s. Its traffic model is based on a psycho-physical driver behavior model for longitudinal vehicle movement developed by Wiedemann, which combines a perceptual model of the driver with a vehicle model and a rule-based algorithm for lateral movements. It can analyze traffic operations for various geometric configurations, traffic demands, control strategies, etc. (Gomes, May, and Horowitz 2004, PTV 2009a). VISSIM also offers an additional module which provides Component Object Model (COM) interface for use with external programming environments. It is possible to access most objects available with VISSIM, to manipulate their attributes, and to automate certain tasks in VISSIM by executing COM commands (PTV 2009b).

3 EXPERIMENTAL DESIGN

A simple VISSIM traffic network is utilized, as seen in Figure 2. All links are one-way, from the left to the right, with every vehicle entering at the leftmost network node and exiting at the right most network node. Vehicles are generated at the leftmost node at constant headways according to the desired traffic flow rate. The desired speed of generated vehicles is 48kph. Upon generation each vehicle is assigned as a participating or non-participating vehicle based on the desired participation rate (i.e., penetration ratio). Each participating vehicle is also assigned an initial route through the network as described in section

2.3 while each non-participating vehicle is assigned a route through the network randomly. In our example two routes are possible; the upper set of links (link 1 to link 2 to link 4 to link 6) or lower set of links (link 1 to link 3 to link 5 to link 6). The non-congested travel time of the two routes is approximately equal.

The departing link (link 6) is a two-lane road minimizing possible vehicle conflicts at the link 4/link 5 merge. Also, the length of the entering link (link 1) is set such that during a DCA model run the length of at least one time bin will pass while the vehicle is on the link. This ensures that the vehicle will undertake the route choice decision process at least once prior to the decision point at the link 2/link 3 split. Each simulation experiment is run for 3600sec, with the reported results the average of ten replicates. System update time interval (i.e., database time bin) is an important factor for timely update of traffic state with sufficient traffic information, which is set 3 minutes in this paper.

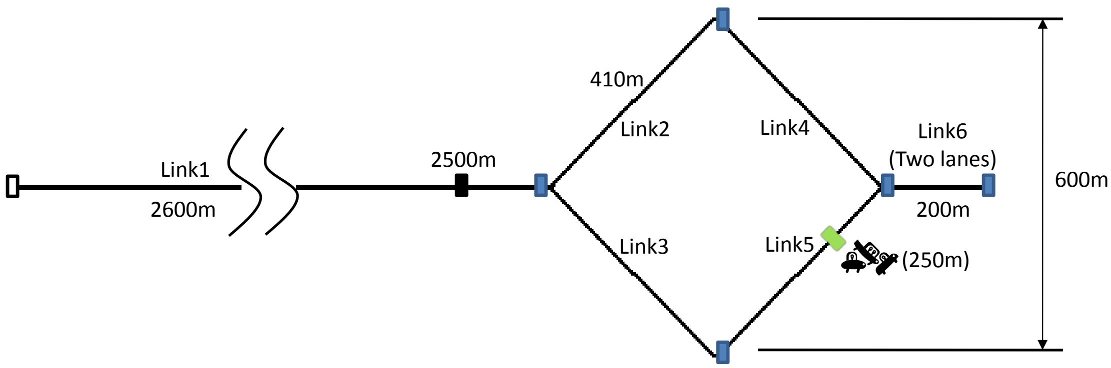


Figure 2: Layout of notional traffic network

Table 1 provides the legend for locations identified in Figure 2 where link travel time data is collected or vehicles select or update their route choice.

Table 1: Functional network information

Symbol	Activity	Function	Time	Vehicle Type	ATIS Model
	Vehicle entry	Vehicle generation	Constant headway based on flow rate	P[1], NP[2]	CA1, CA2, DCA
		Route selection	On new vehicle generation	P, NP	CA1, CA2
	Final route selection	Last location at which selected route may change	At presence of vehicle at location	P	DCA
	Detector	Record upstream link travel time	At presence of vehicle on detector	P	CA1, CA2, DCA
	Incident location	Creates bottleneck, increasing travel time on link.	1000sec to 2000sec with one vehicle release per 90sec	P, NP	CA1, CA2, DCA

Note: 1 = participating vehicle, 2 = non-participating vehicle

The sensitivity of the models to three underlying factors, namely traffic flow rate, communication radio range, and penetration ratio are considered in these experiments. Table 2 lists the parameter ranges considered. For brevity the reported results in this paper are drawn from the 720vph traffic flow scenarios, however, similar trends are seen in the 300vph and 524vph experiments. In addition, to examine the performance of the proposed ATIS models under various traffic states a traffic incident is modeled on link 5. The traffic incident is in effect from 1000sec to 2000sec, releasing vehicles at a rate of 1 every 90seconds.

Table 2: Factors parameter ranges studied

Parameter	Range	Involved ATIS model	Note
Traffic flow	300, 514, and 720vph	CA1, CA2, DCA	12, 7, and 5 seconds respective constant headway
Communication radio range	300, 400, and 500m	DCA	Omni-directional and no signal interference
Penetration ratio	10% to 100%	CA1, CA2, DCA	10% increment

4 RESULTS AND ANALYSIS

It is anticipated that for each of the ATIS models under study as traffic flow rate, communication radio range, and penetration ratio increase, a higher percentage of participating vehicles will be afforded the opportunity to re-route should an alternate path provide a lower travel time. The following analysis attempts to confirm this expectation as well as determine the efficiency of each approach in providing participating vehicles with accurate data in a sufficiently timely manner that it may be used for routing decisions.

It is noted that the current experimental design is intended for initial exploration of the proposed architecture. As such the volume scenarios are selected such that sufficient excess capacity exists on each route and that vehicle rerouting will not result in a notable increase in travel time on the new routes. Thus, the impacts of driver route changes (i.e., a sufficient number of drivers changing routes such that the new route breaks down) is not captured (Wahle, Bazzan, Klugl, and Schreckenberg 2000, Mahmassani and Chen 1991). In addition, complete driver compliance is assumed, that is, drivers change routes whenever a shorter path becomes available and there is no subset of drivers who choose to remain on their chosen route regardless updated travel time information. Thus, participating vehicles are assumed to use a greedy optimization with the probabilistic tendencies of some drivers changing routes and others not only reflected by use of the penetration ratio (Bazzan, Oliveira, Klugl, and Nagel 2008). Given the understanding of the basic architecture from this initial analysis future investigations will explore the proposed ATIS behavior on larger networks containing a more realistic set of potential driver responses and congestion conditions.

4.1 CA1 and CA2 Route Travel Time

To gain a general sense of the CA models behavior Figure 3 displays the CA1 and CA2 upper and lower route travel times for a single replicate run of the scenario with an entering traffic volume of 720vph and a penetration ratio of 100%. The impact of the incident is clearly seen on the lower route in both methods. The incident impact is first noted at approximately 1200 seconds, 200 seconds after the start of the incident. This delay results from a participating vehicle not sending an updated travel time to the traffic information center until it successfully traverses the subject link. Thus, 200 seconds after the incident initiation the first participating vehicle successfully passes through the incident and completes its traversal of link 5. Therefore, from time t = 1000 seconds to t = 1200 seconds participating vehicles may continue to select the lower route, unaware of the incident. The impact of this delayed identification of the incident in the database is seen in the increasing travel times reported from time t = 1200 seconds until slightly after the incident clearance at t = 2000 seconds. These travel times are from vehicles already on the lower route when the incident occurred with those that enter the route between t = 1000 seconds and t = 1200 seconds, unaware of the incident. After approximately t = 1200 seconds no additional participating vehicles enter the lower route under either CA1 or CA2, as the upper route travel time is reported as lower. In the CA1 model vehicles will not enter the lower route anytime during the remaining simulation run. As the last reported travel time is reported as the current estimate for links in which no data is reported even well after the incident clears the route travel time will continue to be as high in the CA1 model. This link will not be traversed by a participating vehicle therefore no after-incident travel time will be sampled to allow for a reduced estimated travel time. In contrast, the CA2 method will eventually allow for participating vehicles to traverse the lower route as any time bin with no travel time data reported will utilize historical travel time data, which is the non-incident travel time. Thus, after four time bins pass without a travel time reported the estimated travel time will again be the non-incident travel time.

It is noted that the CA2 estimated lower route travel time is consistently lower that the CA1 travel time during the incident period. This is a result of the averaging in the CA2 method, where in this incident scenario the actual travel time is continuously increasing during the incident duration. However, the vehicles experience the same travel time in both methods.

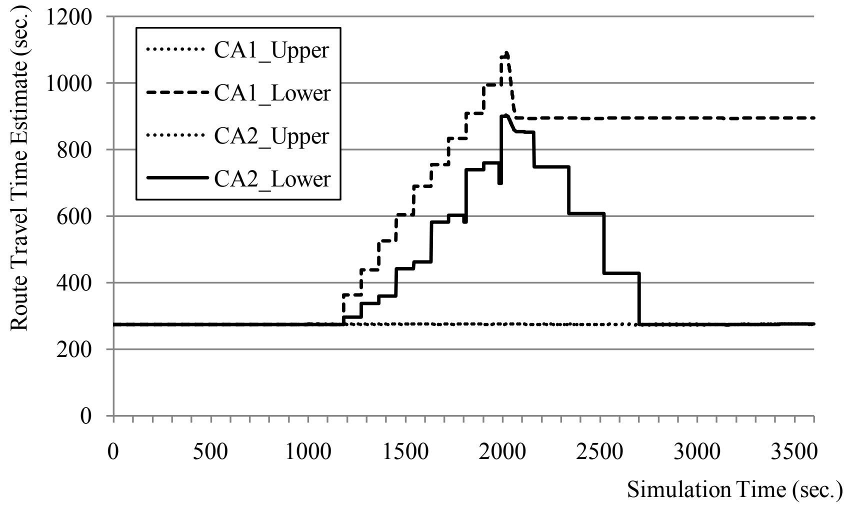


Figure 3: Route travel time estimate comparison in the CA model

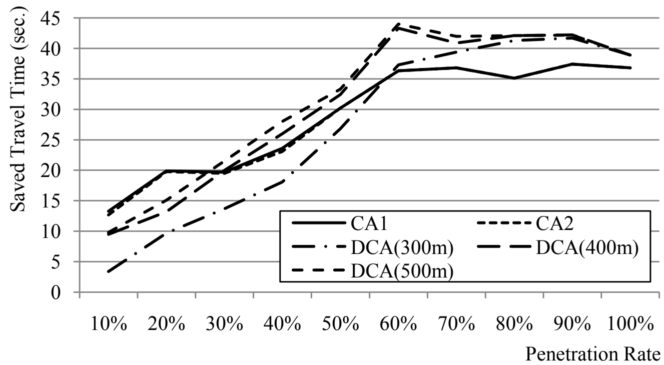
4.2 Average Travel Time Difference of Participating and Non-participating Vehicles

Figure 4 shows the average travel time difference between the base scenario (i.e., no vehicle rerouting) and the developed ATIS models and Coefficient of Variation (CV) (i.e., standard deviation / mean) of simulation outputs, for an entering traffic demand of 720vph over penetration ratios ranging from 10% to 100%. At low penetration rates and short radio ranges high travel time savings variance is identified for participating and non-participating vehicles, with standard deviations exceeding the mean savings (i.e., CV greater than 1) at the lowest levels (i.e., 10% and 20% penetration). This indicates that at the lower penetration rates the travel time savings under all systems is unreliable. As the penetration ratio increases the CV decreases, providing for a higher reliability in the travel time savings. Similar results are seen for the lower demand scenarios, however, higher penetration rates are needed to lower the CV as the number of participating vehicles in a system is a function of both the penetration rate and overall demand.

It is seen that the travel time of participating vehicles in all ATIS models tend to be lower than that of the base scenario (Figure 4a). Furthermore, as expected, as the penetration ratio increases the travel time savings increase. At a penetration ratio of approximately 60% the average saved travel time and CV of participating vehicles stabilizes, implying a limited marginal benefit to currently participating vehicles with the addition of more participating vehicles in the fleet. It is also noted that the non-participating vehicles receive some benefit (Figure 4b), as participating vehicles are able to avoid the incident, reducing the overall demand at the incident location and subsequent incident related congestion. Also, as there are fewer non-participating vehicles in the network as the participating vehicle's penetration ratio increases the number of vehicles on the incident link decreases, reducing the overall incident impact.

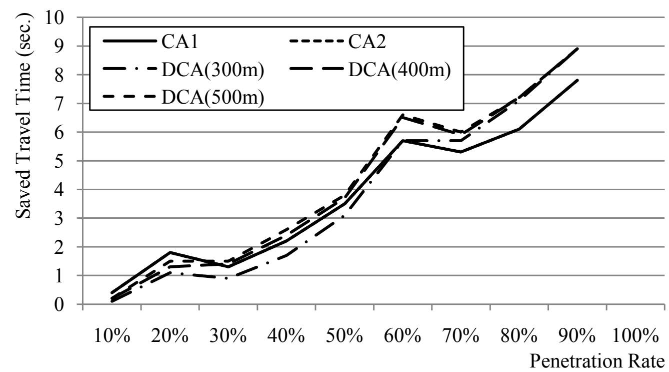
It is observed that the CA1 and CA2 models provide nearly identical time savings. However, it is noted that the CA1 model results in a higher number of participating vehicles that are re-routed during the simulation period. This is a result of the method used by each model to impute the travel time for a link when no data has been received for the respective update interval or time bin, as discussed in Section 4.1. As the lower route travel time never returns to the non-incident travel time in CA1 the vehicles will continue to be re-routed even after the incident has cleared. If the non-congested travel times of the two routes were not similar this behavior could significantly impact the travel time benefit of CA1. While not reflected in the travel time findings of this study this inability to update travel time information on routes without participating vehicles represents a potentially significant limitation in instrumented vehicle only ATIS based systems.

Finally, as expected, as the radio range in the DCA model increases the travel time savings improve. However, it is interesting to note that at lower penetration ratios the CA models provide greater travel time savings while at the higher penetration ratios the DCA models provide higher savings. This is a reflection of the trade-offs between the two methods. At lower penetration ratios information passing is less efficient in the DCA model (as message hopping opportunities are fewer), resulting in the on-board databases having incomplete data. As the penetration ratio increases the dynamic communication network becomes increasing robust with participating vehicles receiving an increasing percentage of the available travel time data. However, the CA database will contain the data from all participating vehicles regardless of the penetration ratio. Thus, at lower penetration ratios the CA approach is able to make more informed decisions. However, the DCA model has an inherent advantage in that a vehicle may change its route while in the network. Thus, as the penetration ratio increases the CA advantage is lessened and DCA mid-trip re-routing capabilities become increasingly advantageous, ultimately providing greater travel time savings at higher penetration ratios.



	10 %	20 %	30 %	40 %	50 %	60 %	70 %	80 %	90 %	100 %
CA1	**1.5**	0.9	0.6	0.3	0.3	0.3	0.1	0.2	0.2	0.1
CA2	**1.6**	0.9	0.6	0.6	0.3	0.3	0.1	0.2	0.2	0.1
DCA(300)	**2.4**	**1.0**	0.8	0.5	0.5	0.4	0.3	0.3	0.3	0.3
DCA(400)	**1.7**	0.9	0.8	0.6	0.4	0.4	0.2	0.3	0.3	0.3
DCA(500)	**1.7**	0.9	0.8	0.6	0.4	0.4	0.2	0.3	0.3	0.3

(a) Travel time savings and Coefficient of Variation for participating vehicles



	10 %	20 %	30 %	40 %	50 %	60 %	70 %	80 %	90 %	100 %
CA1	**1.3**	**1.0**	0.6	0.5	0.4	0.4	0.3	0.4	0.2	NA
CA2	**1.3**	**1.0**	0.6	0.5	0.4	0.4	0.3	0.4	0.2	NA
DCA(300)	**2.4**	**1.3**	0.9	0.4	0.5	0.4	0.4	0.4	0.4	NA
DCA(400)	**1.7**	**1.2**	0.8	0.4	0.5	0.4	0.4	0.4	0.4	NA
DCA(500)	**1.6**	**1.1**	0.8	0.5	0.4	0.4	0.4	0.4	0.4	NA

(b) Travel time savings and Coefficient of Variation for non-participating vehicles

Figure 4: Average saved travel time comparison and Coefficient of Variation (720vph flow rate scenario)

4.3 Long-term Accident Case

As seen in section 4.1 this paper presents the performance of the developed CA1 and CA2 models given a realtively short-term traffic incident. However, given the observed behavior it is natural to investigate how the developed models would respond to a more significant incident. Thus, a longer incident duration experiment was designed as outlined in Table 3. The resulting route travel times for the CA models is shown in Figure 5.

Table 3: Simulation parameters for long-term traffic incident case

Parameter	Value
Simulation time	7200sec
Traffic incident	From 1000 to 6000sec
Traffic flow	300vph
Penetration ratio	100%
Involved ATIS models	CA1 and CA2

As the CA1 model utilizes the last recorded link travel time for links where no travel time is reported for an update interval the lower route travel time estimate is constant after the last participating vehicle assigned to the lower route exits the incident location at approximately 1800 seconds. However, the CA2 method utilizes historical non-incident data when no new data is available. Thus, for the given CA2 parameters, 12 minutes after the participating vehicle at time 1800 seconds departs the incident location the impact of the incident on travel time is removed completely from the travel time database. This will result in a participating vehicle potentially selecting the lower route, even though the incident still exists, as witnessed by the second increase in travel time on the CA2 lower route starting at approximately 3000 seconds. This is the same behavior that would be witnessed with the DCA model. Once a participating vehicle successfully traverses the incident location the CA2 travel time database is again informed of the incident and participating vehicles again start re-routing around the incident. The behavior of both the CA1 and CA2 models highlight a significant drawback to a ATIS system based solely on participating vehicle data. That is, some subset of participating vehicles must traverse each link to maintain reasonable travel time estimates. Otherwise, participating vehicles will continue to avoid links, reducing system efficiency, well after an incident has cleared (e.g., CA1 lower route travel time estimate in Figure 3) or vehicles will be required to "probe" the previously congested link to determine if the incident still exists, potentially requiring a participating vehicle to use a highly inefficient route (e.g., CA2 lower route travel time estimate in Figure 5).

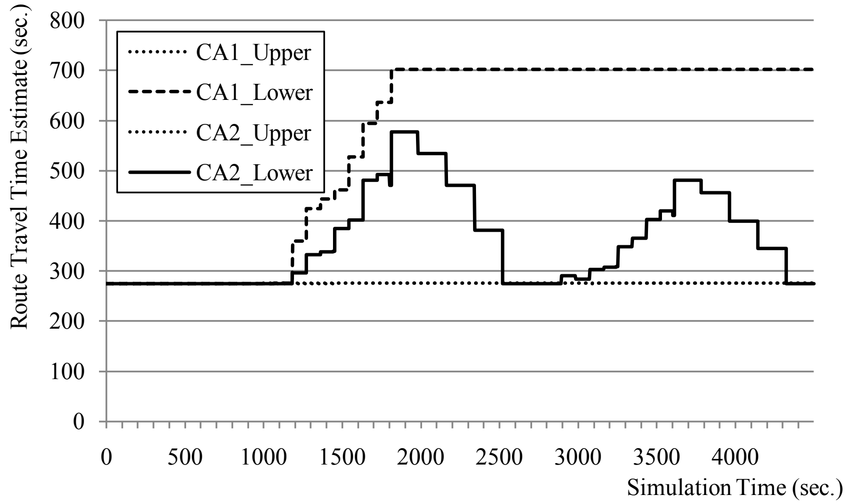


Figure 5: Route travel time estimate comparison in the long-term traffic incident case

5 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 on a simple traffic network were investigated. In this ATIS DRGS implementation travel time information is stored in space-time memory residing in the traffic information center (CA models) or on-board each participating vehicle (DCA model). Participating vehicles communicate travel time updates with roadside units or neighboring participating vehicles. Using the travel time data gathered the central database or on-board databases are updated, allowing for the calculation of revised routing information.

To evaluate the ATIS models with wireless communication a simple traffic network was constructed and implemented using an off-the-shelf microscopic simulation model, VISSIM and VISSIM COM, assuming an ideal communication environment with no signal interference and no data loss during the communication process. Included in the experimental design was the impact of an incident. Through the experiments it was noted that there is some delay between the incident start and its effect influencing the CA or DCA route travel time estimates. The delay resulted in some participating vehicles not receiving updated travel time estimates in a sufficiently timely manner to allow them to avoid the incident related congestion. Also noted as part of this experiment was a drawback particular to vehicle based data collection. That is, that some subset of participating vehicles must traverse each link to maintain reasonable travel time estimates. Otherwise, participating vehicles will continue to avoid links, reducing system efficiency, well after an incident has cleared or vehicles will be required to "probe" the previously congested link to determine if the incident still exists, potentially requiring a participating vehicle to use a highly inefficient route (CA2). However, even with these drawback all three proposed system were seen to provide travel time saving benefits to both participating and non-participating vehicles. In order to investigate more general system characteristics (e.g., impacts of driver rerouting, traffic information flooding problems, etc.) the developed ATIS model should be tested on a larger and more complicated traffic network, representing a more realistic set of route choices and incorporating the potential of alternate route congestion due to route switching. As part of this investigation methods will be explored to reduce the computational demand on each participating vehicle as with increasing network scale the ability to process and pass required information in real time may become a bottleneck. Also, a hybrid ATIS DRGS can be suggested for better system performance, incorporating both vehicle-to-vehicle and vehicle-to-roadside communication within the same infrastructure. In addition, more efforts should be made to improve the communication model with more realistic communication-related parameter values. Lastly, this paper employs 3-minute system update time interval and aggregated travel time over the previous four time bins to predict the short-term traffic state information. The impact of these design parameters on system performance should be investigated.

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