Emergence of Private Advanced Traveler Information Service Providers and its Effect on Traffic Network Performance

UCI-ITS-TS-WP-01-10

Jun-Seok Oh
R. Jayakrishnan

Department of Civil and Environmental Engineering and Institute of Transportation Studies University of California, Irvine
jsoh@uci.edu, rjayar@uci.edu

December 2001

Institute of Transportation Studies
University of California, Irvine
Irvine, CA 92697-3600, U.S.A.
http://www.its.uci.edu
Emergence of Private Advanced Traveler Information Service Providers and Its Effect on Traffic Network Performance

Jun-Seok Oh and R. Jayakrishnan

Institute of Transportation Studies, University of California, Irvine, California 92697-1000, USA

Abstract. This paper examines the emergence of supply side competition in the ATIS industry and marketability of private ATIS. First, this study describes an architectural model in which the ATIS companies collect network information from their subscribers while providing them with real-time traffic information. It is followed by a simulation study on competition and cooperation under multiple private and public information agencies. This study focuses on analyzing the interaction between information agencies and its effect on traffic system performance.

INTRODUCTION

Recent advances in telecommunications technologies are expected to influence widely the area of advanced traveler information systems (ATIS). Specifically, private enterprises taking advantage of the technological advances will play a more important role in the area of ATIS. The emergence of cellular and wireless technology, GPS systems and Internet over the past few years has made many different potential designs for traffic information supply possible. Private companies are already entering the market for traffic information supply, though it is not yet altogether clear whether such businesses can be sufficiently profitable. It is also quite possible that private companies can enter the traffic information supply industry without relying on traffic data from public agencies. However, most of the earlier and existing insights and predictions on the benefits of ATIS in urban networks were based on the expectations that massive public expenditure would be needed for such systems. Thus there is a need to study the effects of multiple agencies being involved in the ATIS "market-place".

Whether the private industry enterprises in traffic information supply would be successful, or whether they actually would cause overall benefits for urban transportation are questions that remain unanswered. The US society has shown positive response towards information technologies and the industry is making available products and services to the "consumer" and services to the "consumer" (convenience) and within their control (e.g. computer keypads or other "convenience" gadgets). The first initial growth and success of Internet commerce is a case in point towards consumer acceptance of information technology, though it has slowed down a bit recently. There is perhaps enough indication that consumers in the traffic area (drivers) will accept a certain level of ATIS technology and perhaps pay for it, at least initially. It is however unclear how reliable such technology needs to be, to ensure that the momentum would continue till the technology reaches sufficient market penetration. The interplay between market penetration and information reliability arises as a key issue here.

The emergence of private information suppliers implies that there would be multiple information vendors in the ATIS market. In a market with multiple information suppliers, their cooperation and competition will also affect the market as well as the performance of the information system. Most existing literature however seems to look at ATIS as a one-supplier system, mostly run by a public agency, and few has examined the possibilities of multiple information supply schemes existing except for some of the work on multiple-user class traffic assignment which allude to some theoretical possibilities.

This paper examines the supply side competition in the ATIS industry and marketability of private ATIS. First, this study describes a plausible architectural model in which the ATIS companies collect network information from their subscribers while providing them with real-time traffic information. It is followed by a simulation study on competition and cooperation under multiple private and public information agencies. This study uses a relatively comprehensive simulation model for the analysis of ATIS that explicitly models multiple advanced traveler information agency systems to analyze interaction between information agencies and its effect on performance.
EMERGENCE OF SELF-SUSTAINABLE PRIVATE ATIS

Background and Vision

Recent advances in communication technology allow mobile communication and its application to Advanced Traffic Management and Information Systems (ATMIS). In the late 1980’s, many felt that there would be commercial dynamic route guidance using in-vehicle navigation systems (IVNS) operating by early 1990’s. A review (1) identified four main reasons why the optimism of the late 1980’s would not be followed by actual success. These were primarily the deficiencies in the

- Availability of mapping data
- Establishment of good traffic monitoring networks
- Choice of communication method
- Need for integration with other ITS service

Despite efforts during 1990’s to overcome these bottlenecks, IVNS have yet to reach their predicted level of market penetration. There have been several research and operational tests of traveler information systems: TransTrek in Orlando, ADVANCE in Chicago, SWIFT in Seattle, TravInfo in San Francisco Bay area in the U.S., Euro-Scout, IntraGSM in Europe, VTCS in Japan, etc. (2) Some car manufacturers already provide in-vehicle navigation systems—though none currently have the ability to give current-conditions accuracy enough in the U.S. They sell these products mostly as gadgets for “peace of mind” of not getting lost in the network. These are available currently primarily in rental cars or as an option in higher-priced or luxury. A low level of demand seems from lower effectiveness compared to high price for most drivers. Market potential will not be achieved until real-time traffic is integrated into the route guidance. For example, the success of the Japanese VTCS (Vehicle Information and Communication System) is partly due to a good digital data communication system that promptly provides the latest traffic information to drivers via car navigation systems from beacons installed on the roadside. US public agencies have not invested in such infrastructure, however. The lack of reliable traffic monitoring systems to support dynamic route guidance is an essential reason why commercial dynamic route guidance systems have been relatively slow to come up in the U.S. Currently ATIS companies face multiple challenges (3):

- The underlying product—real-time traffic information cannot be manufactured in a controlled environment.
- The data are variable in scope and quality and are provided in non-standardized format.
- No established consumer market exists for real-time traffic information other than radio broadcast reports.

Telematic platforms, such as in-vehicle PCs and navigation devices, are important venues for sale of traffic information services. Recent trends toward wireless communication and potential of mobile phones as traffic probes will significantly affect the ATIS business model. Several new venues for ATIS service are emerging on the market: mobile hand-held computer, Internet access, GPS, and in-vehicle information systems. All these rely on the evolution of the Wireless Applications Protocol (WAP) which enables mobile, direct two-way delivery path to customers and enables faster personalized Internet access. Second-generation cellular systems have also been put into operation, and most of them are providing wireless Internet services. The technologies have promised availability of data transmission services (4), including GSM II (Global System of Mobile communication), CDMA (Code-Division Multiple Access), TDMA (Time-Division Multiple Access), and CDPD (Cellular Digital Packet Data).

As the Internet has become more and more popular in daily life, web-based sources of real-time traffic information that provide users with pre-trip traffic information and route planning have appeared. It is now possible to consider integrated in-vehicle navigation systems that connect all aspects of the automobile’s maintenance and operating systems with Internet access, entertainment and productivity programs, and mobile two-way voice and data exchange. With such technological advances, it is quite possible that private companies can enter the traffic information supply industry without relying on traffic data from public. The private companies may be able to collect high quality data from their subscribers who are equipped with advanced communication and location devices.
Issues in the EN of Private Information Suppliers

It is no stretch of imagination to expect that private firms selling such hardware can require (one) appropriate pricing mechanism their customers to import it to the supply firm. What market penetration is required for a given private firm to be successful is such an operation? Should or can they rely on public agencies for information, and will that be accurate enough? Can they be successful without sharing information with other such suppliers? - Those are questions currently without clear answers.

There are various pros and cons in encouraging the development of private enterprises for supplying information, especially depending on what form these enterprises would take. The nature of their relation to public agencies managing traffic, the competition among such private enterprises, as well as the required cooperation among them, would drive the success of any future ATIS developments. The technology is finally here now, to bring about ATIS improvements which have been discussed about for a decade and half now, however there are no guidelines available for any public policy-making for the purpose of channeling the private industry emergence towards potentially beneficial directions. There may be reasons to believe that a hands-off approach to this from regulatory and governmental agencies could result in the failure of private enterprises. The main issue deals with the quality and richness of information the private firms have on urban conditions. To what extent should they rely on public agencies for such information? To what extent would they develop their own infrastructure? Can or should they insist that those who have bought their products should act as probes for network condition information? Wouldn't that lead to privacy issues? To what extent should the private firms share information? Should there be regulations on the sharing of such information? Such questions lead to the intricate interplay of technology deployment in urban networks, the stochasticity in urban traffic conditions, the demand for information, and the market penetration of information supply industry products. The first step in analyzing such questions is to model networks with various types of ATIS systems and various kinds of private supply of information.

There are several schemes for ATIS currently being discussed about, some without much details (some even with technical details not available as they are part of patent-pending architectures for traffic information supply). As such, analysts have no clear idea on what will work, as a traffic system is one of the more complicated systems out there - with less than perfect demand prediction schemes and even worse supply/performance prediction models.

Parametric simulation of candidate schemes identified with a fundamental view, based on key variables, could help find very useful insights. Some of these variables are:

- The size of a private firm in terms of the number of customers (equipped cars)
- The coverage areas each have, which is turn determines the accuracy of their information at the path-level (or route-level) in the network (i.e., the information they have on links outside the area could be less reliable)
- How much information is shared (quantifiable parameters)
- Speed, accident flags, etc
- Stochastic errors (more errors assume in the data accepted from other firms?)
- Time delay (data shared comes in at various intervals)
- Whether the technology is based on in-car computations (for instance a Java program computing shortest paths based on latest network link information downloaded to the in-car browser), or whether the computations are done at a central point and downloaded.
- What quality of data is available (GPS position data? Aggregated 30-sec pedestrian loop-detector data? Probe vehicle speed data updated at what frequency? Note that the time factor can be seen as key parameter here)
- Delay in receiving information from public agencies (for instance, accident information may not be available till the traffic agency confirms that one has occurred, from the police and using surveillance)
- Discrepancy between guidance/information predicted for the drivers, versus what they experience (note that if a driving alternative is suggested and it became congested later, the driver can be informed that it was still the best route they could have taken)
This is not an exhaustive list, and this research attempts to identify important parameters such as these, which will affect the performance of private information supply firms. Note that even for some of the proprietary and patent-pending schemes being considered by private firms, the basic characteristics can be brought down to fundamental variables such as above and included in parametric simulations. This is what motivates the work in this paper, as we do not focus on all the above aspects, but look at the key parameters, namely, market penetration, information reliability and time delay in using the information.

Advent of Private IVNS and ATIS Architecture

Conventional architecture of ATIS and relationship between private information vendors and public agencies is based on the assumption that public agencies are responsible for the significant infrastructural investment for traffic monitoring systems. Even though public traffic monitoring systems based on pavement loop-detector technology exist in many urban and freeway contexts for traffic management, these systems are possibly not sufficiently accurate for real-time route guidance purposes. Specifically, the limitations in the quantitative monitoring of the surface street traffic conditions have been a bottleneck in deploying dynamic route guidance systems. Despite the inaccuracies in public agencies’ traffic information, private companies who do not have traffic monitoring capability had to rely on public information for their business. As seen in the TravInfo field operation test (FOT) project, the private companies were concerned that public information systems could become a business competitor if ATIS made travel information widely available through the wireless data broadcasting system, direct modern links to individuals and personalized automated phone reporting systems. The problem surfaced mainly because of the private companies’ reliance on public traffic data.

In the new era of information innovation, the role and capability of private companies can and will be different. Thanks to the two-way communication capability in in-vehicle system and possible embedded location devices such as based on GPS and other inertial navigation and dead-reckoning systems, it will be possible for private IVNS companies to use their subscribers as probes for traffic condition monitoring. Such capability is expected not only to affect ATIS architecture but also change the ATIS market. The private sector can now potentially provide high-quality traffic information services without relying on public sector’s traffic data, if they have acceptable market penetration.

It is presumed that various private-sector information providers open up the market using Internet and wireless technology for real-time vehicle guidance. The overall structure presented here is based on the simple concept that the information provider collects traffic information from their subscribers while providing them with information. Each consumer of information becomes a probe vehicle for the information provider. Thus the more subscribers, the better the information system is. There could be five steps to deliver route guidance information from raw data collection to the end users. The possible scenarios are dependent on the subjects to process the probe vehicle data and to provide the information. The main issues here are: 1) data communication between vehicle and system, 2) public and private partnership and 3) centralized or decentralized decisions.

![Figure 1 Possible Data Flow in IVNS](image)
Table 1 Scenarios of Data Flow in IVNS by Information Subjects

<table>
<thead>
<tr>
<th></th>
<th>Type I</th>
<th>Type II</th>
<th>Type III</th>
<th>Type IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Probe Vehicle</td>
<td>Car</td>
<td>Car</td>
<td>Car</td>
<td>Car</td>
</tr>
<tr>
<td>Data Processing</td>
<td>Car</td>
<td>Car</td>
<td>Private ISP &amp; Public</td>
<td>Public</td>
</tr>
<tr>
<td>Data Integration</td>
<td>Private ISP</td>
<td>Public</td>
<td>Public</td>
<td>Public</td>
</tr>
<tr>
<td>Route Information</td>
<td>Private ISP</td>
<td>Private ISP</td>
<td>Private ISP</td>
<td>Car</td>
</tr>
<tr>
<td>End Users</td>
<td>Driver</td>
<td>Driver</td>
<td>Driver</td>
<td>Driver</td>
</tr>
</tbody>
</table>

In line with Figure 1, four basic scenarios can be established as in Table 1. The major differences among them are the subjects for data processing, data integration, and routing decision. While type I is a solely private system, the type IV is a public system that is similar to Japanese VICS. Type II and type III are cooperative models between private and public.

Proposed Private IVNG System

This study proposes a model of private IVNS capable of network monitoring while providing information. There are two layers in the private information supply system: local system and central system. While the local systems communicate with individual vehicles directly, the central system communicates with local systems for local data collection and global information distribution. Also, the central system shares traffic information with other private companies as well as public agencies. The data flow of the proposed system is depicted in Figure 2.

![Diagram of Data Flow in Private IVNS](image)

Figure 2 Overall Data Flow in Private IVNS

SIMULATION STUDY OF PRIVATE ENTERPRISES AND THEIR COOPERATION AND COMPETITION

Simulation Model for Analysis

Simulation experiments are conducted via a traffic simulation model, DYNA4SMART (DYnamic Network Assignment-Simulation Model for Advanced Road Telematics) that is a discrete time mesoscopic simulation model for ATMS applications (6). It is designed to model traffic pattern and evaluate overall network performance under real-time information systems. DYNA4SMART used in this study is an enhanced version that incorporates multiple information sources and their algorithms for generating route guidance schemes.
This research analyzes private IVNS that are capable of monitoring network conditions from their subscribers. In this analysis, link travel times to provide via IVNS are estimated only from the subscribers, and they are instantaneous travel time information. There are several route guidance approaches from a simple feedback approach to a comprehensively predicted approach using dynamic traffic assignment (7). This paper takes the simple feedback approach with instantaneous travel time information, which may reflect private sectors’ information systems at least during the early stage.

Also the model takes stochasticity of individual vehicle’s speed into consideration. While the prevailing link speeds are calculated from the speed-density relationship as same as the conventional macroscopic traffic model, individual vehicles’ speeds are assumed to be Normally distributed with the prevailing speed and a given variance.

\[ u_{ai} = u_i \cdot (1 + N(0, \sigma)) \]  

\[ u_i \] = speed of vehicle i on link l

\[ u_{pl} \] = prevailing speed of link l

\[ N(0, \sigma) \] = Normal distribution with mean 0 and standard deviation \( \sigma \)

Several measures of effectiveness (MOEs) are considered for the evaluation of IVNS capability in terms of traffic monitoring and information reliability. First, the network coverage rate by probe vehicles is evaluated as follows:

\[ \text{Coverage} = \frac{\sum_{l} \sum_{t} \delta_l}{T \cdot L} \]  

where, \( \delta = \begin{cases} 1, & \text{if probe vehicle exists on link } l \text{ during time step } t \\ 0, & \text{otherwise} \end{cases} \)

\[ T \] = total number of time steps

\[ L \] = total number of links

The accuracy of data can be measured by error rate of link travel time estimation (LTE) defined as follows:

\[ \text{LTE} = \frac{\sum_{l} \sum_{t} \left( \frac{|u_{pl} - u_{100\%}|}{u_{100\%}} \times 100 \right)}{T \cdot L} \]  

where, \( u_{pl} \) = travel time on link l during time t with a probe rate of 100%

\( u_{100\%} \) = travel time on link l during time t with probe rate of 0 % and data collection interval t

In route guidance, the estimated link travel times are certainly important because they are directly used for optimal route selection and route travel time estimation. There have been many studies on travel time estimation using GPS (9) and probe vehicle requirement for reliable estimation (10). However, a more important measure is route travel time itself that constitutes reliability of the information system, and the accuracy of route travel time is the most important factor from travelers’ point of view. Note that the instantaneous route travel times cannot be same as actual travel time that travelers will experience as discussed before and the information is updated during their trip. The error rate of the route travel time (RTE) is defined as:
\[
\text{RTE} = \frac{\sum_{i=1}^{V} \left( \frac{t_i - t'_i}{\eta_i} \right) \times 100}{V}
\]

where, \( \eta_i \) = experienced travel time for vehicle \( i \)'s trip
\( t_i \) = informed travel time at the beginning of vehicle \( i \)'s trip
\( V \) = total number of vehicles

Network Monitoring Capability and Performance of Private IVNS

First, this study investigates the capability of private IVNS in terms of traffic network monitoring and information accuracy. In this study, simulation experiments are conducted with two different networks: a simple corridor network and the Anaheim network that is a general large-size urban network. The simple network consists of two main corridors, three crossing streets and three interchanges as shown in Figure 3 (a). The Anaheim network consists of 440 nodes, 1060 links, and 42 zones as shown in Figure 3 (b). Of these, 42 zones, 15 zones are internal surface zones, 15 zones are external surface zones, 7 zones are external freeway zones, and 4 zones are for special-event facilities, such as Disneyland, Convention Center, Angel Stadium and Arrowhead Pond sport arena.

For the private IVNS, the network monitoring capability is directly affected by the market penetration, as higher market penetration implies a higher fraction of probe vehicles. The traffic data aggregation interval is another factor influencing the network monitoring capability. As shown in Figure 4, the network monitoring capability of private IVNS is evaluated with respect to these two key variables. Those important findings from the results, some of it quite as expected, are as follows:

- Naturally, the network's coverage increases with increase of the market penetration and the information update interval. A longer update interval results in the larger network coverage because more links that a vehicle traverses are included.
- The link travel time estimation error decreases as the market penetration increases, but more drastically when the update interval is shorter.
- For long update intervals (3-5 minutes), the link travel time estimation error does not decrease much once market penetration goes beyond a certain level.
- When market penetration is lower than 20%, the longer update intervals show smaller estimation error because of the higher variance and unrepresentativeness of travel times estimated with fewer probe vehicles.
- The route travel time information error decreases up to 20% of market penetration, but the errors with long update intervals (3-5 minutes) increases when the market penetration is higher than 20%.

In the performance evaluation of private IVNS, two measures are considered: overall travel time and the guided drivers' travel time savings over the unguided drivers. As shown in Figure 4, the total system cost generally decreases as the market penetration increases, in both networks. However, in the small corridor network, the costs with long update intervals increase again when the market penetration is higher than a certain level. This can be explained by the over-reaction problem due to the time lag in the small network, and it is in line with results well known in the past (Mammasani & Jayakrishnan, 1991).

From the information suppliers' and the users' point of view, their subscribers' or their own travel time saving is more important. In both networks, the guided drivers' travel time saving over the unguided drivers monotonically decreases. The last figures in Figure 5 depict travel times of guided drivers, unguided, and overall.
Figure 3 Two Test Networks
Figure 4 Network Monitoring Capability and Information Accuracy

Note: Numbers in the legend box indicate information update intervals
Corridor Network

Anaheim Network

Figure 5 Performance of Private IVNS

Note: Numbers in the legend box indicate information update intervals
Comparison between Multiple IVNS

For the case of route guidance provided by multiple information service providers (ISPs), possibly from the private sectors, this study investigates the effects of the competition and cooperation in the market. Assuming that there are two information vendors and that their market shares remain same regardless of the changes in total market penetration, this study analyzes three scenarios with respect to market share:

- Scenario 1: Each ISP possesses 50% of market share.
- Scenario 2: One ISP possesses 75% of market share and the other 25%.
- Scenario 3: Two ISPs cooperate together by sharing their information.

In the cooperative system case, ISPs use other ISPs' probe information as well, so that they are able to improve their sample rates for travel time estimation. This means that multiple ISPs share their information for better travel time estimation. However, in the competitive system, ISPs are competing, so that individual ISP uses only its subscriber as travel time estimation.

As in Figure 6, the link travel time estimation error decreases as market penetration increases for all cases, and naturally ISPs with higher market share show lower error in travel time estimation. An interesting finding is that the errors in route travel time information are almost a minimum at the real market penetration of about 20% as shown in Figure 7. It seems that 20% of market penetration is enough to maintain a sufficiently accurate level of route travel time information. This implies that ISPs may need to cooperate to maintain certain accuracy of information, but they do not need to cooperate once they reach a certain level of market penetration. The net market penetration of the ISP with 25% share is only 5% when the total IVNS market penetration is 20%, but their information accuracy is not significantly worse than the other that has 75% market share (net market penetration 15%). However, note that the difference between the two ISPs' information accuracy is significant when the total market penetration is greater than 20%. That is, an ISP with higher market share has advantages at the early stage of IVNS deployment, however, the advantage decreases as the overall IVNS market penetration increases.

Figure 8 compares overall travel time saving under different market scenarios. Even though the differences between market structures affect the accuracy of travel time information, the overall network performance is not as sensitive to this, as it is to the total market penetration. It is natural that the differences between market structures in the overall time saving are not significant at the high total market penetration. It was expected that the full cooperative system might outperform the competitive systems especially at the low total market penetration, but no significant difference was identified in the simulation results.
Figure 6 Link Travel Time Estimation under Two Information Suppliers

Note) 25 = ISP with 25% market share while the other vendor’s market share is 75%  
50 = ISP with 50% market share while the other vendor’s market share is 50%  
75 = ISP with 75% market share while the other vendor’s market share is 25%  
100 = All ISP share their information.
Figure 7 Route Travel Time Information under Two Information Suppliers

Note: 25 = ISP with 25% market share while the other vendor’s market share is 75%
50 = ISP with 50% market share while the other vendor’s market share is 50%
75 = ISP with 75% market share while the other vendor’s market share is 25%
100 = All ISP share their information.
Figure 8 Overall Travel Time Saving under Two Information Suppliers

Note: 50 = 50% market share for both ISP
     75 = One ISP with 75% market share, the other 25% market share
     100 = All ISP share their information.
The next simulation experiment is conducted to find the effect of market penetration and information update interval on the information accuracy under two ISPs. Agency 2 is assumed to do business with given information of quality (update interval) and market penetration while agency 1 updates information every minute with varying market penetrations. As shown in Figure 8 (a) and (b), the difference between two ISPs in information error is larger when the market penetration of the agency 2 is lower as in (b). However, the difference is even larger when the ISP updates information with longer interval as in (c) and (d). This indicates the information update interval is more important under the sufficient market penetration.

Figure 9 Route Travel Time Information Accuracy under Two Information Suppliers
Note: Agency 1 updates information every 1 minute.

Comparison between Public and Private Agencies
Emergence of IVNS affects the benefit of other information devices, such as radio or CMS. Well-established information systems reduce relative benefits of IVNS. This circumstance can be understood as competition between private and public. While radio and CMS are considered public information devices, the IVNS dealt in this study are considered a type of private information devices. In this experiment, the corridor network is used for analysis of the mutual effects between public and private information systems.

Figure 10 depicts changes in overall travel time saving as the market penetration of IVNS increases. When the market penetration of IVNS is higher than 20%, the additional benefit of other information devices drastically decreases. This implies that other information devices may not be effective when the market penetration of IVNS is sufficiently high (20% in this example).
CONCLUSION

This paper analyzed traffic network under emergence of private route guidance systems. Thanks to recent advances in information technology such as GPS, Internet, cellular, and wireless communication, the private companies will be able to provide route information to their subscribers based on the traffic condition estimated from their subscribers’ GPS information. There are many issues to be discussed in the era of private information suppliers. This research conducted parametric simulation of candidate schemes identified with a fundamental view based on key variables to provide initial set of insights.

Via a simulation model developed for the analysis of multiple ATIS, network monitoring capability and overall performance of private IVNS were evaluated. One of the significant findings in the simulation study was that a market penetration of 20% was a sufficient level for both link travel time estimation and route travel time provision. Interestingly, in the analysis of competition between multiple IVNS, the errors in route travel time information were almost minimized at the total market penetration of 20%, which implies private ISP’s do not need to cooperate once they reach a certain level of market penetration. In the analysis of competition between private and public information systems, the additional benefit of other information devices dramatically decreased when the market penetration of IVNS was higher than 20%. This implies that other information devices may not be effective when the market penetration of IVNS is sufficiently high.

REFERENCE

3. FHWA (2000) What have we learned about Intelligent Transportation Systems?


