Google-Map-Based Online Platform for Arterial Traffic Information and Analysis

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ABSTRACT:

Web-based mapping technologies have been increasingly utilized for traveler information systems. However, most such systems focus on freeways rather than arterials or urban streets. This paper presents a Google-map-based online platform for arterial traveler information broadcast and analysis. This system is named GATI for convenience. Open source web tools and emerging web technologies, such as Ajax, are used to implement the GATI system to ensure its performance and to minimize its cost.

GATI has operated online using the City of Bellevue's data since January 1, 2007. It is not only an arterial traveler information system but also an online analysis tool for urban traffic network. The current version of GATI offers two analysis functions: time-domain analysis and scatter plot analysis. To demonstrate the strength of this platform, three case studies are presented in this paper, one uses historical traffic flow map to identify bottlenecks, one applies before-and-after analysis to evaluate the impact of a snow storm, and the other employs time-series data to evaluate intersection performance. This GATI system, though presented and demonstrated using the City of Bellevue's data, is a general technology that can be applied to other arterial networks.

Key words: Google maps, arterial, traveler information system, traffic flow map, web technology, time-domain analysis, and intersection performance.

1. INTRODUCTION

With technology advances in Intelligent Transportation Systems (ITS), traffic sensing, computing, and communication methods have improved significantly. Consequently, traffic management systems and traveler information systems have become more and more capable of processing a large amount of live traffic data. How to utilize, manage, and represent the data efficiently and effectively becomes a challenging issue for Advanced Traveler Information Systems (ATIS). Well-designed ATIS not only help improve personal mobility and the productivity of transportation systems but also provide useful information for advanced users, such as traffic operators and researchers, who wish to detect the cause and evaluate the impacts of traffic incidents on an urban roadway network.

Most existing traveler information systems developed by state Departments of Transportation (DOTs) have focused on displaying traffic flow conditions on freeways. Examples of such systems are the Puget Sound Traffic Flow Map (Washington State DOT or WSDOT), TransStar (Texas DOT), Caltrans Real-time Freeway (California DOT), and CoTrip (Colorado DOT) *(1)*. As for the arterial or urban street ATIS, little work has been done. The City of Bellevue's traffic flow map is one of the few online arterial traveler information systems developed to date *(2)*. The design of this system contained several creative ideas such as the one that uses advance loop data for arterial performance measurement. Despite its achievements in online arterial traffic information display, Bellevue's system *(3)* suffers from two main drawbacks. The first drawback lies in the un-scaled map. It is very difficult to locate positions or estimate link lengths on Bellevue's traffic flow map due to the fact that the online map is not to scale. The second drawback, which is common to most ATIS, is the lack of interactivity between users and the system. Therefore, some traffic flow map applications started using web-based mapping engines to increase interactivity. For example, the Dallas transportation management center (DalTrans) recently developed a Google-based mapping system with improved web navigation capability to replace their previous dynamic freeway traffic information website *(1)*.

In recent years, online mapping technologies have advanced rapidly and achieved remarkable popularity. Since 2005, Google has developed and distributed an Application Programming Interface (API) toolkit for their mapping services. Hundreds of Google-map-based web applications can be easily accessed via any web browsers with an Internet connection *(4, 5)*. In the field of transportation, Google-map is also increasingly utilized. On Feb. 28, 2007, Google introduced an embedded real-time traffic program that displays congestion conditions on major state routes and freeways in over 30 US metropolitan areas, including Seattle *(6)*. At the current stage, most mapping systems focus on freeway applications and few address issues on urban streets, even though travelers heavily rely on urban streets for their travels. Moreover, these applications typically do not archive data that could be very valuable for transportation research. Even though Bertini et al. *(7)* developed an archived data user service, it still focuses on freeway applications at this moment.

This paper presents a Google-map-based online platform for arterial traveler information broadcast and analysis. An earlier version (Version 1.0) of this online system was introduced by Wu et al. *(8)*. Although the system has been significantly enhanced and expanded, we still prefer using its original name, Google-map-based Arterial Traffic Information (GATI) system, for convenience. In this paper, the authors intend to provide a thorough introduction to the updated GATI system and demonstrate the functions of the system so that their experience can be helpful for developing similar online systems. This paper is organized in five sections: Section 2 briefly introduces system architecture for the GATI system; It is followed by a detailed description of technologies used for implementing the system in Section 3; In Section 4, three case studies are introduced to demonstrate the analytical functions of GATI; and in the final section, findings of this study are summarized and future studies are recommended.

The current GATI system (Version 2.0) can be accessed from the website for the University of Washington Smart Transportation Application & Research Laboratory (STAR Lab) located at http://www.uwstarlab.org.

2. SYSTEM ARCHITECTURE

Our goal for the GATI system design was to make it not only an online traveler information system but also a powerful traffic analysis tool. This required strong server and database support. As shown in Figure 1, the complete system architecture is primarily composed of three parts: servers in the City of Bellevue, servers in the STAR Lab, and client applications. Each of the three parts is explained in detail below:

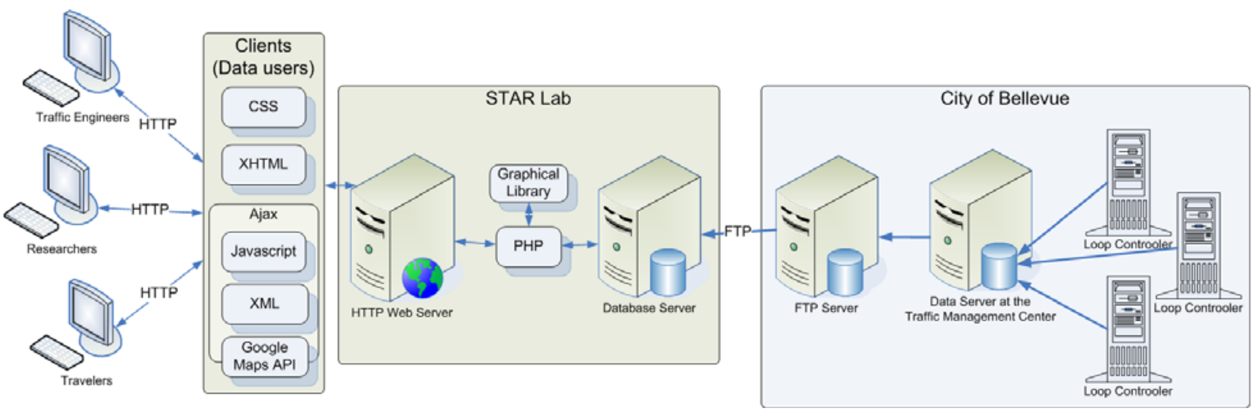


FIGURE 1 GATI system architecture

Servers in the City of Bellevue

Servers in the City of Bellevue include a data server and a File Transfer Protocol (FTP) server. The data server is located in the Traffic Management Center (TMC) in the City of Bellevue. Raw data retrieved from the remote communication units of signal controllers are processed in the data server *(9)*. The processing work is repeated periodically and the processed traffic data are stored in a FTP server for user agencies, such as the STAR Lab, to access. This FTP server can be accessed by any FTP client software. Details on data type, content, and format are explained in the implementation section of this paper.

Servers in the STAR Lab

The GATI system servers in the STAR Lab contain a database server and a Hypertext Transfer Protocol (HTTP) server. PHP Hypertext Preprocessor (PHP) played an indispensable role for setting up a communication bridge to connect these two servers. More details are provided in the implementation section of this paper.

Clients

Clients interact with the HTTP server through a specific user interface (UI) designed for server-client communications. Several web techniques and languages, such as Cascading Style Sheet (CSS), Extensible Hyper-Text Markup Language (XHTML), and Ajax, shorthand for asynchronous JavaScript, and Extensible Markup Language (XML) are used for the UI development. Ajax, coined in 2005, is a growing web development technique for creating interactive web applications *(10)* and has been widely used in web-based systems. Google Maps API is the core display engine of the system. It makes the map rendering and feature drawing fast and reliable *(11)*.

3. IMPLEMENTATION

Data organization, interface design, and services setup are three major implementation issues. Implementation details of the GATI system are described in this section.

3.1 Data Organization

The database system of GATI manipulates live and archived data from the City of Bellevue. In addition to traffic data and their coding formats, other information, such as the location of each intersection and link-intersection information were also collected from related documents provided by the City of Bellevue. All these data sets are stored in a database specifically designed to support clients' queries at the front end and administrator's analysis at the back end of the GATI system. Since the database plays an important role in efficient operations of the GATI system, it must be carefully designed and implemented to ensure system performance.

Bellevue's Traffic Data

According to *(2)*, the City of Bellevue operates 177 signalized intersections and has 160 signals connected to Bellevue's TMC where a centralized signal system is operated. Traffic conditions and congestion levels are determined by the occupancy data collected from the advance loop detectors normally located at 100 ~ 130 feet (30.5 ~ 45.7 m) upstream from the stop bar at each approach. In the TMC data server, the congestion levels are further translated into color codes. On Bellevue's traffic flow map, color codes are used to display five different congestion levels ranging from a low congestion level of 1 to a high level of 5. All data received and processed by the TMC data server are compiled into a Comma-Separated-Value (CSV) file every minute and saved in the FTP server for user agencies to download. The CSV file contains real-time information for each roadway section, which is referred to as "link". One-minute CSV contains eight columns: the link numbers, link IDs, smooth volumes, smooth occupancies, cycle lengths, cycle plan numbers, color codes, and incident codes. Since April 17, 2006, the CSV data files have been used by the City of Bellevue to display arterial traffic flow conditions on its real-time arterial traffic flow map *(3)*. Bellevue's traffic flow map received broad attention because, at that time, few cities in the U.S. provided real-time traffic information for local arterials. More details can be found in *(2)*.

Data Tables

Keeping all data in CSV files will not be efficient for constructing flow maps since it will take a long time to parse the files and consume a lot of memory space. As a result, a database is designed to hold all data. The first table created in the database is the traffic data table. All data in this table were imported from the CSV files. This table, however, lacks location information for each link and for drawing a link between the start node and end node. Therefore, the second table for holding intersection location data and the third table for storing intersection-link relationship data are constructed to support the traffic data table. Location of each intersection can be manually input by using the Google-map based intersection locator developed in this system. This web program employed the GXmlHttp object to enable asynchronous interactive locating tasks. Meanwhile, link-node (or link-intersection) relationships between intersections are constructed. More details can be found in *(8)*.

Data Updates

After locating intersection coordinates and constructing the link-intersection relationship table, data are organized in a correct format. As mentioned earlier, a real-time data update engine, FTP Downloader, was developed for the GATI system and executed in the HTTP server. It plays three roles: (1) archiving CSV files in the dated folders, (2) updating the database through the Open Database Connection (ODBC), and (3) generating real-time XML files for real-time flow map display. While downloading the CSV file every minute, FTP Downloader also update database tables. Additionally, FTP downloader can also allow users to update data manually. Data has been continuously updated in real-time since January, 1st, 2007.

Database Performance Enhancement

Database performance is a crucial issue since a huge amount of data has been imported into the database and 20 million tuples are added to the database tables every month. Choosing the right storage engine is an important issue. Considering querying performance, MyISAM is chosen for our application as it is more efficient than other storage engines such as InnoDB, the most commonly used transactional storage engine. Indexing is another significant issue in performance enhancement. Since the flow map is often shown with varying time, the “time stamp” attribute was indexed. The index uses B-tree data structure. Based on these parameters, querying 469-row link data for a specific minute requires only 0.05 seconds within which nearly 20 million rows of data are searched.

3.2 Interface Design

Figure 2 shows a snapshot of the user interface of the GATI system. The left side shows the main interface. The right side shows the proposed graphical analytical tools currently include the time-domain analysis tool and the scatter plot analysis tool.

On the main interface, the map controls located in the top-left corner allow users to choose the level of detail by zooming in and out. Users can drag the map to any place of interest to see the variation of flow maps in detail after the query process. In the top-right corner, users can choose different modes of maps, including the map mode, satellite mode, and hybrid mode.

Each mode has its advantages with regards to visualizing data for users. The rectangular side pane on the right is the control panel that handles input from users. It is divided into two parts. The upper part is used to display the original Google Map, the Intersection Locator (for administrative use), and the real-time flow map.

The Intersection Locator is the interface to build up the intersection table. The lower part is the historical flow map query interface for querying archived data or launching the graphical analysis tools. For the historical map query, one can view the flow map for the selected time directly on the Google Map. Users can easily refer to the traffic congestion legend to distinguish the congestion level for each link. Another feature on the side pane is the Google Maps address textbox, which uses the built-in geocoder engine to locate the address of interest *(11)*. Basically, users can input the exact address, the zip code or geographical coordinates to locate a specific spot promptly. In the lower-left corner is a message board that can show the XML-type query results or error messages.

As for the graphical analysis tools, they are triggered by the buttons on the side pane. The time domain plot tool can display a series of data for the user selected time period on a chart. Scatter plots are a handy tool for investigating relationships of occupancies and volumes. Different constraints can be specified through the interface. For example, a user can specify a signal timing plan so that only occupancy and volume data corresponding to the timing plan are plotted.

FIGURE 2 The GATI system user interfaces

3.3 Services Setup

Figure 3 depicts the flow chart of the GATI system. The Apache HTTP server (version 2.2.4) was chosen as our web server because Apache has become one of the most popular HTTP servers and is highly configurable and extensible with third party modules. The GATI system is composed of six modules. Each module is circled by a dashed line and described as follows:

(1) Data processing module: as described in the previous subsection, a C# program, FTP Downloader, was developed and installed in the HTTP server. FTP Downloader downloads traffic flow data every minute from the FTP server at the City of Bellevue. The data is stored in

MySQL database. Meanwhile, an XML file is generated for updating the real-time flow map and the original CSV file is archived in the hard drive.

(2) Data storage module: This module is centered by the MySQL database server (version 5.1) for data management. It interacts with the data processing module and the computing module for receiving and providing data. The archived CSV files and the XML file are also handled by this module.

(3) Computing module: This module contains two interpreters, PHP (version 5.2.0) and JavaScript/Ajax. The former resides in the HTTP server supporting the query tasks from the user input module. The latter resides in users' browser to interpret the script retrieved from the HTTP server. In this case, Ajax technology can allow users to asynchronously retrieve the XML file using PHP and JavaScript. See (Purvis, 2006) for details.

(4) Graphical analysis tool module: JpGraph *(12)* and the Graphic Development (GD) Library *(13)* are used to illustrate the results from the computing module. This module is highly reliant on computations performed by PHP. The graphical analysis tools introduced in subsection 3.2 are realized in this module.

(5) Information display module: This module uses Google Map API to display traffic information on Google maps. Google Map API serves as an independent bridge connecting the HTTP server and the clients.

(6) User input module: The module is the UI that receives and transmits users' commands. User inputs are parsed by the computing module before proper actions are initiated.

Note that the web software packages mentioned above, such as PHP and MySQL, are open-source (free) applications and under active development.

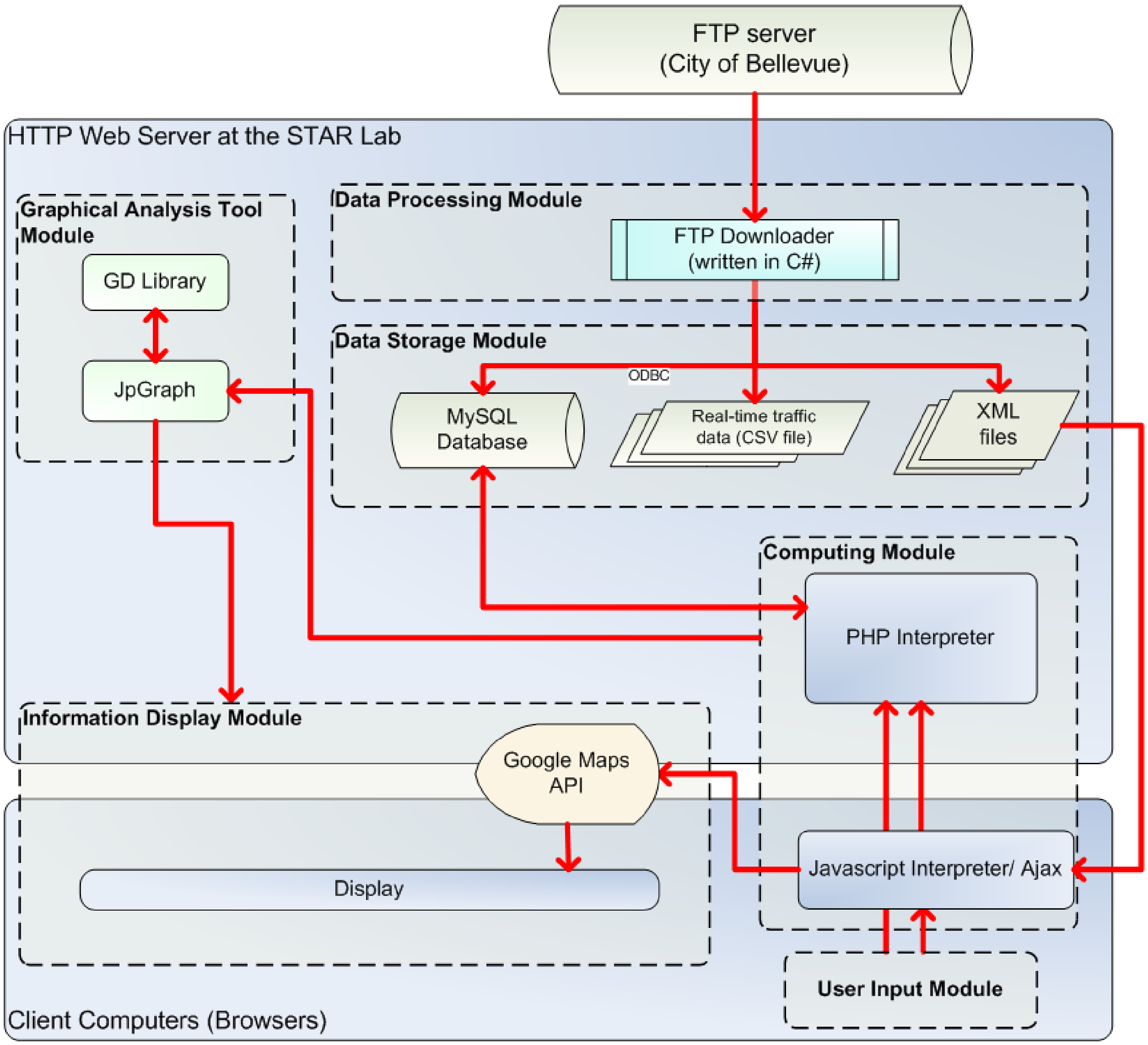


FIGURE 3 The flow chart of the GATI system

4. EVALUATION AND APPLICATIONS

Assessment of the arterial traffic conditions is the first step for improving its performance. The GATI system can play diversified roles in traffic information broadcast and analysis. For roadway uses, the GATI system serves as a real-time travel information system. For transportation professionals, it can be utilized as an online arterial analytical tool. In this section, we use three example applications to demonstrate the capabilities of the GATI system.

4.1 Real-Time and Historical Flow Map

As mentioned earlier, the GATI system can display either real-time or historical traffic flow maps. Regular road users can use this system for planning trips before leaving their destination.

Advanced users (e.g. traffic professionals) can use the system for specific studies, such as the variation of traffic congestion level for a specific link.

By using this GATI system, bottleneck locations for a user-specified time period can be easily identified by viewing the corresponding historical flow maps. Take the afternoon of July 25, 2007 for example. A snapshot of the traffic flow map for the selected date is shown in Figure 4. After monitoring the real-time flow map and comparing it with historical results, one can observe that Intersection 30 (116^{th} AVE & NE 8^{th} Street) has recurrent congestion at the eastbound approach. Intersection 49 is a bottleneck for both the eastbound and westbound traffic during noon and afternoon peak hours. The phenomenon draws our attention for further investigation. We will revisit Intersection 49 using the scatter plot tool in Subsection 4.3.

Furthermore, malfunctioning detectors can also be visually identified on the flow map. For example, the loop detectors on 8^{th} Street between 116^{th} AVE and 120^{th} AVE had stopped detecting vehicles for days. Such malfunctioning loops typically show extreme outputs, e.g. 0 occupancy or extremely high occupancy, and stay in the same level for a long time without any change.

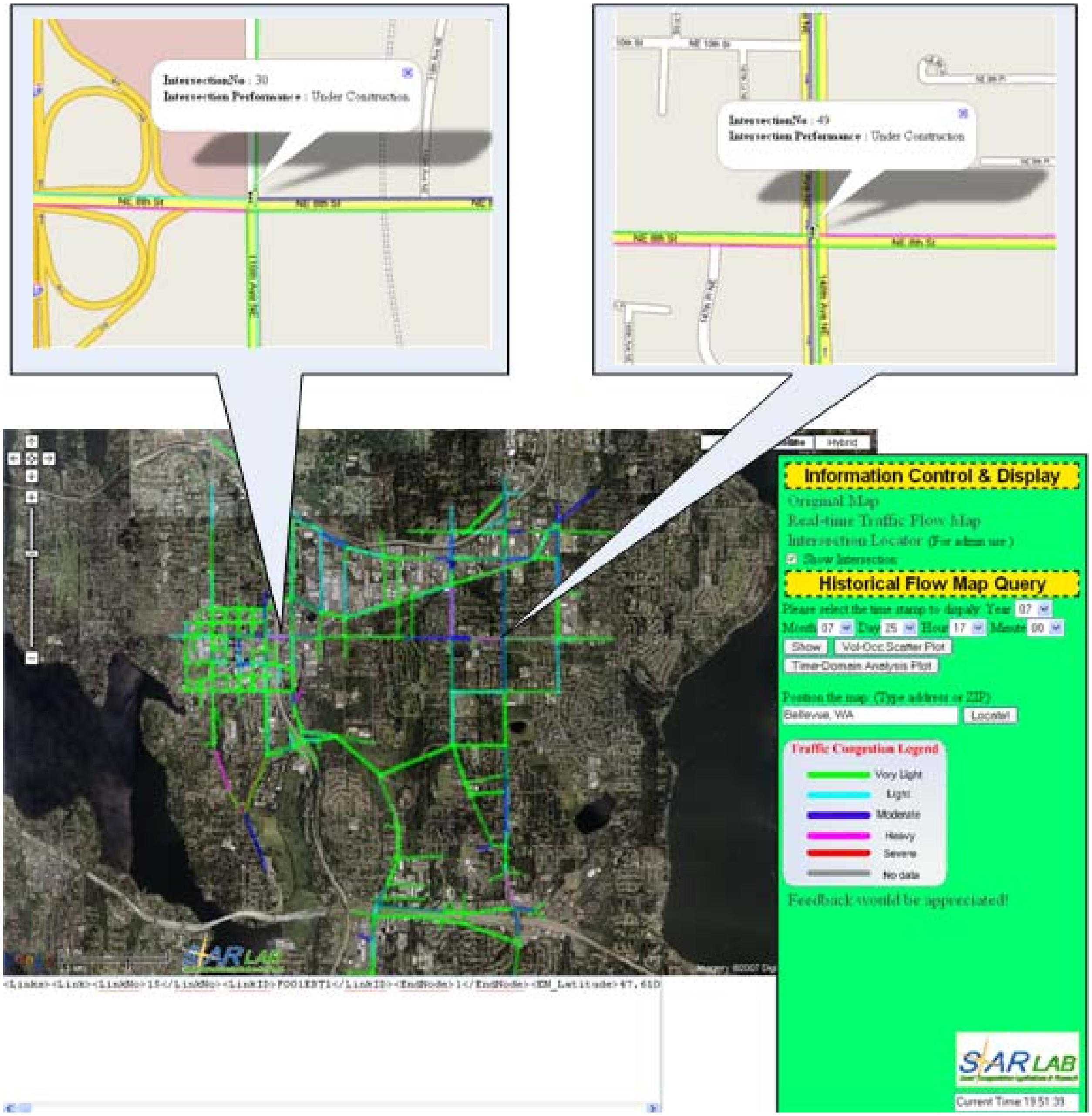


FIGURE 4 Google-based traffic flow map

4.2 Time-Domain Analysis

In addition to the function of displaying traffic flow map online, the GATI system also functions as a data analysis toolkit for roadway network traffic analysis. For example, a traffic operator can use GATI to understand the impacts of certain incidents or harsh climate changes (e.g. a snow storm) on urban street network performance. In order to demonstrate the capability of the graphical analysis tools in the GATI system, a before-and-after snow storm analysis is conducted and presented here.

A good example is the harsh snow storm hit the Greater Seattle area in January of 2007. As reported by the Seattle Post Intelligence *(14)* on January 9, 2007, the authorities warned that the storm would be coming soon. In the morning of January 10, 2007 (Wednesday), roads were a little slippery as expected after light snow and traffic movements were normal. However, it started to snow heavily in the evening and the roadway network was soon covered by snow. Road surface became so slippery that many accidents occurred and most roads were blocked by stopped or abandoned vehicles. Meanwhile, road users were warned by news agencies that temperatures were expected to drop below 30°F and drivers should be aware that roadways, especially elevated roadways, could be treacherous on the following day (Thursday, January 11, 2007) *(15, 16).*

As mentioned earlier, the GATI system offers a time-domain plot tool that can be used to observe the impact of the snow storm by examining traffic conditions before and after. In this analysis, every link parallel to the NE 8th AVE was also examined using this tool effortlessly. The results were fairly consistent. Take the eastbound traffic at Intersection 49 for example. Figure 5 was generated automatically by this tool in seconds. It shows the time series values of volume and occupancy for the three days that covers the before-and-after storm period. Link information is shown at the top of the figure. The left-hand scale is for occupancy and the right-hand scale is for volume. As shown in Figure 5, these time-domain curves clearly reflect the fact that both volume and occupancy decreased significantly on Thursday due to the effect of severe roadway conditions as well as the large number of abandoned vehicles on freeways or highways. Even during the afternoon peak hours, traffic volumes were remarkably low. On Friday, the weather became better and roads had been cleared. Therefore, the commuting traffic started to return to normal.

By examining more roadway links of interest, we can identify key corridors that people actually use during snow storm. Understanding the usage levels of roadway links during snow storm helps transportation agencies develop emergency traffic response plans for inclement whether conditions.

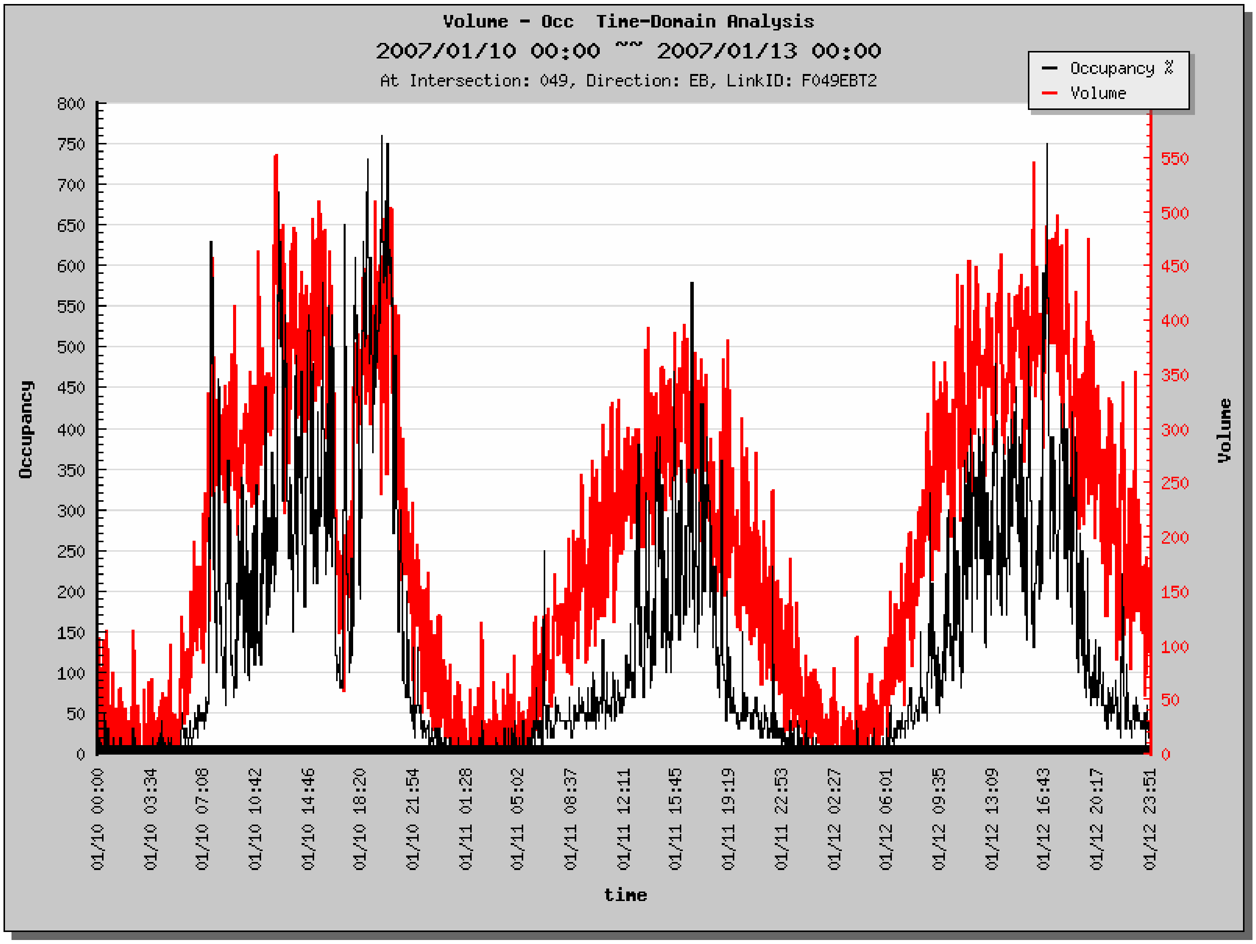


FIGURE 5 Time-domain analysis on volume and occupancy

4.3. Intersection Performance Assessment

As introduced earlier, the GATI system is also capable of generating scatter plots for examining the relationship between two variables. As shown in Figure 4 and described earlier in Subsection 4.1, Intersection 49 suffers congestion problems during noon and afternoon peak hours. It would be interesting to know why this intersection is congested and whether congestion can be mitigated. Therefore, this intersection was chosen as a study site to further demonstrate this application. This intersection has a uniform layout: one left turn, one right turn and two through lanes at each approach. In this case study, only through traffic is considered.

Determining Critical Occupancy

In Figure 6, an example of the volume-occupancy scatter plot is shown using one month's worth of data (42566 sample points using one-minute data). The unit for x-axis is volume (vehicles per hour per direction) and that for y-axis is occupancy (percentage of time the loop is occupied by vehicles). In order to compare the performance of different links (approaches) at the same intersection, an occupancy threshold (O_{th}) called critical occupancy should be determined for each approach in advance. Assuming the uniform vehicle length assumption holds, occupancy and density hold a linear relationship. Consequently, the relationship between volume and occupancy is approximately linear when traffic is light and speed is constant. However, when volume reaches a certain level, speed starts to drop and the linear relationship between occupancy and volume is broken. This volume-occupancy relationship is illustrated in Figure 6. The solid line indicates the linear relationship stage of the two variables, which corresponds to the condition of free flow speed. The ending point of the linear relationship is termed the "turning point". The corresponding occupancy of the turning point is referred to as the "critical occupancy". Those sample points above the critical occupancy are considered situated in a congested condition. The turning point should be located in the dashed circle in Figure 6. However, accurately locating this point is not easy. Fortunately, underestimation or overestimation of the critical occupancy does not affect the performance evaluation significantly, as long as all comparisons for the same approach use the same threshold. The following analysis further explains this projection. The rest of the indices shown in the upper-left corner of Figure 6 will be explained in the subsection of performance measurement indexes.

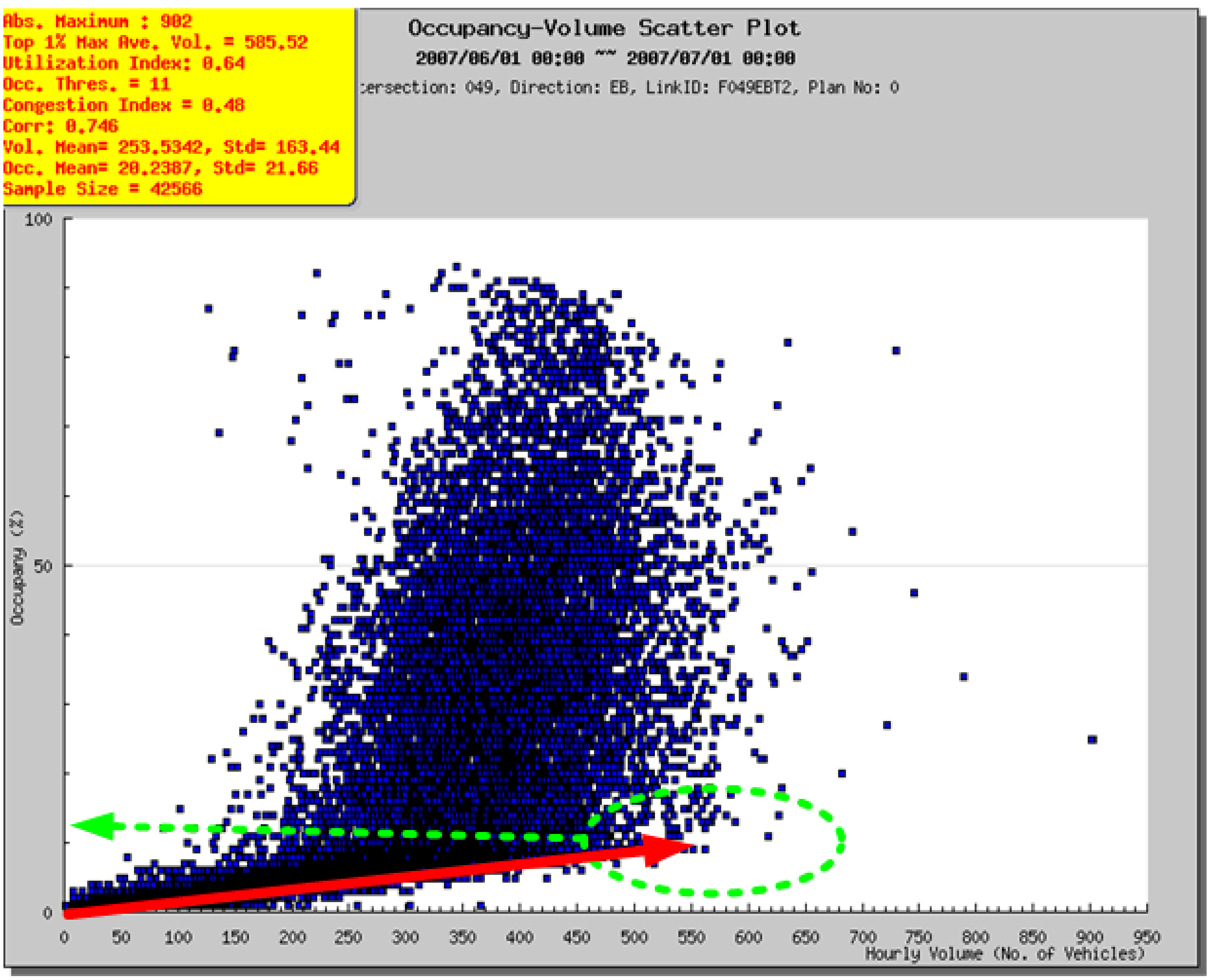


FIGURE 6 Sample volume and occupancy scatter plot

Performance Measurement Indices

Various performance indices are defined for evaluating the performance of the study intersection.

- Basic descriptive statistics: Mean volume, mean occupancy, and corresponding standard deviations are provided for users' reference. Moreover, the maximum volume and top 1% averaged volume will also be provided.
- Pearson's correlation coefficient *(17)*: This is known as one of the best measures of linear association between two variables. This index can be used to measure the linearity between the volume and occupancy before occupancy exceeds its critical value. Once occupancy is over the critical occupancy, the correlation between volume and occupancy drops. Equation (1) is used for calculating this index.

$$r = \frac{\sum_{i=1}^{n}(O_i - \bar{O})(V_i - \bar{V})}{\sqrt{\sum_{i=1}^{n}(O_i - \bar{O})^2 \sum_{i=1}^{n}(V_i - \bar{V})^2}} \quad (1)$$

Where O_i is the occupancy of a sample point, $\bar{O}$ is the mean occupancy of all sample points, V_i is the volume of a sample point, $\bar{V}$ is the mean volume of all sample points, and n is the number of sample points.

- Congestion index: Congestion index (I_c) is defined as the number of sample points with an occupancy value higher than the critical occupancy divided by the total number of sample points. Congestion index can be calculated using Equation (2). If a signal cycle failure happens, congestion value increases.

$$I_c = \frac{k}{n} \quad (2)$$

Where k is the number of sample points with an occupancy value higher than O_{th}. I_c represents the percentage of time the link is congested.

- Utilization index: Utilization index, I_u, is defined as the average occupancy to critical occupancy ratio. It reflects utilization level of a link. Equation (3) can be used to calculate this index.

$$I_u = \frac{\sum_{i=1}^{n} O_i}{n \times O_{th}} \quad (3)$$

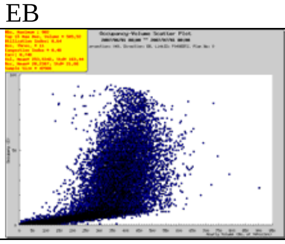
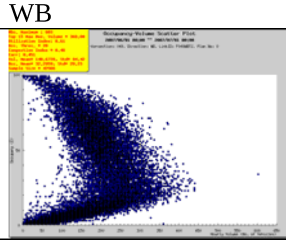
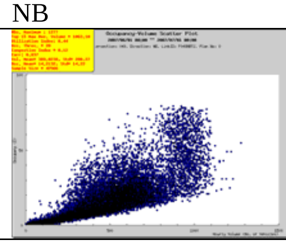
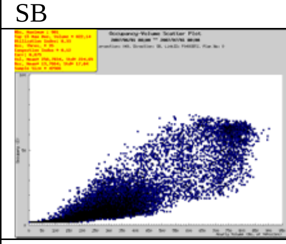
Where O_{th} is the critical occupancy and O_i represents the occupancy value for sample point i. In calculation, if $O_i > O_{th}$, then O_i is set to O_{th}. The higher the utilization index, the more utilized the link. I_u should not exceed 1. Congestion index and utilization index complement each other in reflecting link congestion.

Analysis and Findings

As shown in Table 1, the occupancy-volume relationship for each approach (link) is shown in the scatter plot which uses one month's worth of data (42566 sample points). The purpose of drawing these plots is to determine the critical occupancy value and to investigate the traffic pattern for June 2007. In Table 1, from left to right, eastbound (EB), westbound (WB), northbound (NB) and southbound (SB) links are plotted and related statistics are calculated respectively. The title for each row of the leftmost column is: (1) volume and occupancy scatter plot, (2) the maximum volume within all sample points, (3) average volume of the top 1% volume sample points, (4) utilization index, (5) critical occupancy value, (6) congestion index, (7) correlation coefficient, (8) volume mean (volume standard deviation), and (9) occupancy mean (occupancy standard deviation).

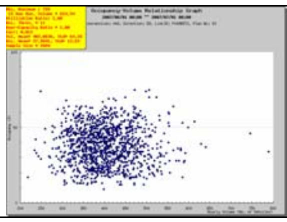
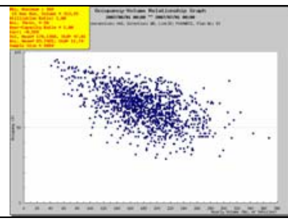
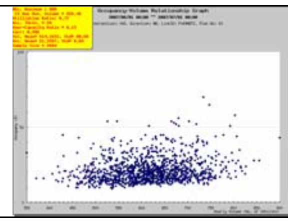
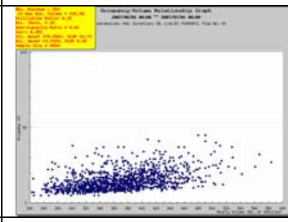
One may notice that WB traffic backs up even under low volume conditions. The congestion index value of 0.48 indicates that traffic suffered severe congestion during 48% of time in this month. On the other hand, EB traffic shows a more vertical trend when volume reaches to higher levels. NB and SB traffic somehow follows a similar trend even without severe congestion during the same period.

Table 1 Results of the Volume and Occupancy Scatter Plot for Intersection 49 during June 2007

	EB	WB	NB	SB
(1)				
(2)	902	683	1277	981
(3)	585.52	368.00	1063.10	822.14
(4)	0.64	0.61	0.44	0.33
(5)	11%	28%	28%	35%
(6)	0.48	0.48	0.12	0.12
(7)	0.75	0.45	0.84	0.88
(8)	253.53 (163.44)	140.67 (94.42)	389.02 (280.27)	258.70 (224.65)
(9)	28.24 (21.66)	32.30 (29.23)	14.21 (14.22)	13.77 (17.84)

As mentioned earlier, Intersection 49 had recurrent congestion during noon and afternoon peak hours. Since this intersection has a lower volume for noon peak hours than that for afternoon peak hours, its timing plan for the noon peak hours draws attention. Table 2 shows an instance of examining the intersection usage when timing plan 43 was in action in June 2007. Timing plan 43 is designed for noon peak hours, starting from 11:16 AM to 1:46 PM during weekdays. The results indicate that WB traffic had suffered from severe congestion even though it had a low average volume (179.14 vehicles per hour). After looking at the downstream intersection traffic conditions, the possibility of backing up from the downstream intersection was eliminated. One can assume that this impact may be from an ineffective signal timing plan. Moreover, WB and EB traffic had a high congestion index (1.00) and utilization index (1.00) because all sample point occupancies were above the critical occupancy value. For NB and SB traffic, the approaches were not fully utilized according to their utilization index values of 0.72 and 0.42, respectively. Fairly low correlation for EB indicates a high level of scatter. A negative correlation for WB depicts a trend of congestion. Compared with EB and WB, NB and SB have relative high correlation values indicating that their traffic movements are more effective. Overall, the results show that the EB-WB traffic and the NB-SB traffic possibly suffered an imbalanced timing plan and thus indicate a need for signal re-timing to improve traffic condition at noon peak hours at this intersection.

Table 2 Results of Occupancy and Volume Scatter Plot for Intersection 49 for Timing Plan 43 during June, 2007

	EB	WB	NB	SB
(1)				
(2)	789	360	900	584
(3)	624.54	313.25	826.46	535.50
(4)	1.00	1.00	0.72	0.42
(5)	11%	28%	28%	35%
(6)	1.00	1.00	0.15	0.01
(7)	0.012	-0.53	0.206	0.45
(8)	482.06 (64.29)	179.14 (47.81)	614.16 (80.68)	370.56 (54.74)
(9)	37.98 (12.63)	63.74 (11.74)	21.34 (8.04)	14.75 (6.45)

5. SUMMARY

A Google-map-based online platform, the GATI system, has been developed and published to provide a real-time traffic flow map for basic users and also to offer a powerful analytical tool for advanced users. Through our implementation, open source software packages proved to be a cost-effective solution for constructing an online data archival system. They also allow developers to create online application programs for data display and analysis in a quick and easy manner. More graphical analysis tools can be incorporated into this GATI platform with little effort and at comparatively low cost. Several case studies have been conducted for demonstrating the capabilities of the online graphical analysis tools. The whole arterial network can be easily monitored by utilizing both the real-time and historical flow maps. The proposed graphical analysis tools enable several important statistical analyses and help identify multiple bottlenecks in arterial traffic network. The performance indexes proposed in this study help measure the performance of urban streets quantitatively and effectively.

In terms of future work, route-wise or network-wise analysis tools should be developed. Combining the prevailing freeway travel information system with the GATI system will provide more complete traffic information for travelers and researchers.

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