

Real-Time Traffic Information Production and Presentation Using GIS-Based Maps

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Abstract

Real-time traffic information for all major roadways in an urban area is one of the most important pieces of information necessary to produce a dynamic route guidance system. Recent GIS development has included many new capabilities for traffic engineering applications. This paper describes work using the latest GIS technology along with advanced traffic analysis and simulation models to produce real-time traffic information. The overall experience has been that GIS has provided great benefit for all phases of development and that new GIS technology has made the presentation and dissemination of real-time traffic information easier and more effective than ever before.

1. Introduction

Geographic Information Systems (GIS) have been used extensively in the field of transportation facility and asset management for quite some time now. However, given that GIS can both model transportation networks and incorporate associated network characteristics directly into the database, it is likely that the next major GIS application for transportation will be advanced transportation network analysis tools that take advantage of GIS-based datasets. Coupled with vehicle and order scheduling, GPS tracking, and logistics support systems, there exists the capability for real-time traffic responsive fleet and mobile workforce management not far on the horizon. It is just recently that GIS has been used with traffic and transportation models for the purposes of area-wide transportation system analysis, forecasting, and evaluation.

Towards this end, Traftools has developed the Traffic Information Engine (TIE)TM to make use of existing real-time traffic data sources in order to simulate and predict both current and future traffic conditions and for the presentation of the resulting traffic information on GIS-based maps. TIETM includes a complete set of traffic system analysis functions that can be used to evaluate and forecast changing traffic conditions whether due to modified traffic lane usage, intersection controls, accidents, special control circumstances, circulation systems, land use, or any other factor affecting the transportation network. Since TIETM can forecast traffic conditions in real-time, it is particularly useful for many applications related to Traveler Information Systems (TIS).

TIETM is a software package that operates in cooperation with the GIS, extracting and requesting data as necessary and providing results for presentation purposes. TIETM utilizes a GIS-based transportation network and requires as data input real-time traffic data and trip matrices representing travel patterns. Analysis and simulation are performed independently of the GIS to produce traffic information such as travel time and speed along major roadways, traffic flow, average delay, and queue length at major intersections or bottlenecks, and dynamic route

guidance that provides the shortest time path between any origin and destination based upon optimized travel times between all possible routes.

The results produced by TIE™ are incorporated into the database and presented on GIS-based maps. By choosing GIS, the maps are interactive and multiple datasets can be linked, related, and presented in real-time. The traffic information is constantly being updated as conditions change; therefore, presentation of the real-time information on static base maps would limit the value of the information and make further use of the data difficult. In contrast, the real-time GIS-based data store allows for many other applications such as the transfer of real-time data directly into fleet and mobile workforce management models to compute new assignments, schedules, and routes, or the provision of real-time traffic information to in-vehicle navigation systems for both everyday and emergency evacuation use.

This paper discusses the use of GIS technology with transportation analysis and simulation models for the production and presentation of real-time traffic information.

2. Network Representation

One of the main purposes of performing in-depth study of traffic and transportation systems is to understand the behavior of each component of the system and its interaction with the whole. This basic understanding leads to a better grasp of the issues and problems surrounding present and future systems.

Normally most traffic/transportation scientists start by modeling transportation facilities such as highway networks first by using links and nodes. Links represent sections of roadway and nodes represent intersections or points of changing roadway characteristics such as the beginning and ends of bridges, changes in pavement width or type, and other variations in geometry or character. Both links and nodes have specific related properties associated with them.

Since standard polylines are typically used to represent roadways, links can easily be modeled using many existing GIS-based maps, but nodes are often more difficult as point features need to be added to store their related characteristics. Fortunately, the design of GIS can handle this new type of geographic information. In the current release of the Traffic Information Engine (TIE)™, nodes are used only to represent intersections and points of changing traffic characteristics. However, this definition can be further expanded as necessary to include other node properties as well.

A. Link Properties

Link properties for study networks, traffic behavioral analysis, and forecasting generally include length, number of lanes, travel time or travel speed at free flow, road section capacity, highway classification, and 3-4 other characteristics that vary from one software program or model to another. In most new models, links are also used to represent other facilities such as rail lines, transit lines, special truck corridors, air lines, etc. Therefore, many link properties have been included in order to be able to simulate travel conditions on these facilities as well.

GIS quite easily accommodates all these characteristics using line and point feature classes with network connectivity determined by geometry using a topological model. Networks therefore include junction and edge objects and all of the relationships between them.

There are a few special link properties used in most traffic studies that have recently been added to GIS models: linear referencing and turn properties. Linear referencing is used for locating sensors and field data along the network in a common measuring system and from particular points of reference; for instance, highway mileposts are a good example of a linear referencing system. Turn properties allow the association of turning characteristics directly with the links involved in the turn movement; these account for most of the basic turning parameters used in area-wide traffic analysis models.

In our models, GIS networks can be used to represent the following:

- One-Way vs. Two-Way Streets
- Road Classification and Characteristics such as Number of Lanes, Distance, etc.
- Grade Separation
- Traffic Characteristics such as Free-Flow Speed, Capacity, etc.
- Intersections
- Turn Penalties and Banned Turns
- Transit Routes (on street right-of-ways)
- Transit Links (on and off street right-of-ways)
- Locations of Sensors on Sections of Freeways and Other Highways

B. Node Properties

A link connectivity model can be used to represent properties of most highway and street intersections, bus and rail terminals, and bus and other transit stops. The model describes properties of links such as which links belong to which network. The network can be connected to other networks at points which may be an end point or any point in between. These connection points are known as nodes and have turn properties associated with them. The turn properties describe basic connecting impedances, such as banned turns or turn penalties. These properties are more than enough to perform standard network analysis and area-wide traffic study such as travel forecasting for strategic planning purposes.

For real-time traffic analysis and prediction purposes, the existing connection properties did not include a few important necessary intersection characteristics, such as type of intersection, intersection control, service rate, etc. Therefore, the dataset needed to be improved. Thus far, the improvement has been accomplished using non-GIS traffic analysis and simulation models to perform these tasks and by modifying the database to accept the results of the models. In the future, the additional characteristics required will be incorporated directly into the dataset by creating a custom feature class that includes all the necessary attributes.

C. Other Properties

Other network level properties that are required for most advanced traffic and transportation analysis include zones, centroids, and special generation/attraction points such as parking, major terminals for rails, trucks, etc. In general, GIS can be used to represent these facilities very well.

Traffic zones, or simply zones, are a geographic unit similar to a census tract or block. While zones are assumed to have homogeneous land use, which is not always the case, the more important assumption is that traffic problems on minor roads in the zone should not affect area-wide trips, since every trip in the zone is aggregated to be generated from and attracted to a centroid in the zone. Therefore, a centroid is just an imaginary point in the zone created for the purposes of simplification of trip movement within and between the zones. For the work that Traftools has done, GIS offers a flexible tool to work with zones because it allows for easy on-screen graphical modification of geographic data and rearrangement of the zones. In order to increase the accuracy of our traffic information, Traftools traffic zones are much smaller than the zones typically used in normal traffic forecasting studies.

The representation of special generation/attraction points such as rail and other transit terminals and parking facilities is more difficult than zones and centroids. Traftools has considered these to be another form of node and consequently, node properties needed to be developed. For the present time, the Traffic Information Engine (TIE)TM uses non-GIS traffic analysis models to perform the task of special analysis and the results are then transferred for storage and presentation in and from the GIS spatial database system.

3. Traffic Representation

Traftools developed the Traffic Information Engine (TIE)TM to work in cooperation with GIS-based software programs. TIETM includes the following capabilities:

- Automatic processing of real-time data feeds
- Automatic integration of incident reports (road closures, special events, accident reports, road construction, etc.) directly from law enforcement and other agencies in real-time
- Manual data entry of incidents by level of severity at the point of occurrence to predict for changing traffic conditions at that specific location and throughout the entire urban area
- Incorporation of selected traffic characteristics particular to the local network in order to better simulate traffic conditions
- Combination of matrix estimation models with data convergence algorithms at selected locations to control new estimated matrices
- Assignment models to produce initial traffic demand on most major roadways in the area
- Macro simulation models to analyze traffic conditions in greater detail along congested networks in order to better replicate traffic conditions and produce more accurate predictive values (traffic information)

- Production of useful traffic characteristics such as travel time, speed, and flow on all major roadways and average delay and queue length at selected intersections in real-time
- Prediction of speed and flow on HOV and designated special use lanes separate from general use lanes
- Forecasting of altered traffic patterns both for specific locations and the whole control network due to high profile events such as sports and concerts or after an incident occurs
- Computation of new travel paths for trips that may pass through an area affected by incident(s) to avoid congestion
- Inclusion of public transit networks and flows on the same or separate right-of-ways; TIE™ can be used to study bus and rail transit travel times, speeds, and effects due to congestion or when an incident occurs (on street right-of-ways)

The Engine operates in conjunction with the GIS-based network, both utilizing data from the GIS model and providing results for graphical presentation purposes. Network modifications and manual data input can be made using ArcMap. The Engine automatically takes in real-time data for analysis and simulation to produce traffic information in real-time. The Engine then transfers the results into the GIS database from which it can be distributed to the Internet via ArcIMS.

Presentation of the results using GIS-based mapping software yields flexible and appealing visualization options. Roadway networks and traffic condition information displayed with GIS-based software can take advantage of the many useful features that GIS-based mapping products such as ESRI ArcMap and ArcIMS have come to include: the ability to zoom in and out to the desired scale and to pan to specific locations, customization of multi-color coding schemes, symbolic and text labels, varying line thicknesses for different features such as roadway classifications and levels of congestion, and support for as many layers of information as necessary to provide just the level of detail required. Special capabilities include image and video rendering for roadway camera feeds, information streaming and extraction, geocoding for address matching and providing point-to-point directions, and spatial and attribute queries on underlying data. Most importantly, GIS software programs allow for customization of the graphical interface for many forms of presentation media. The output of the Traffic Information Engine (TIE)™ is designed to be delivered via the Internet on high-quality GIS maps, but can be provided to lower bandwidth and limited graphical capability devices such as pagers and cell phones as well. Figure 1 depicts the process by which real-time traffic information is produced and disseminated.

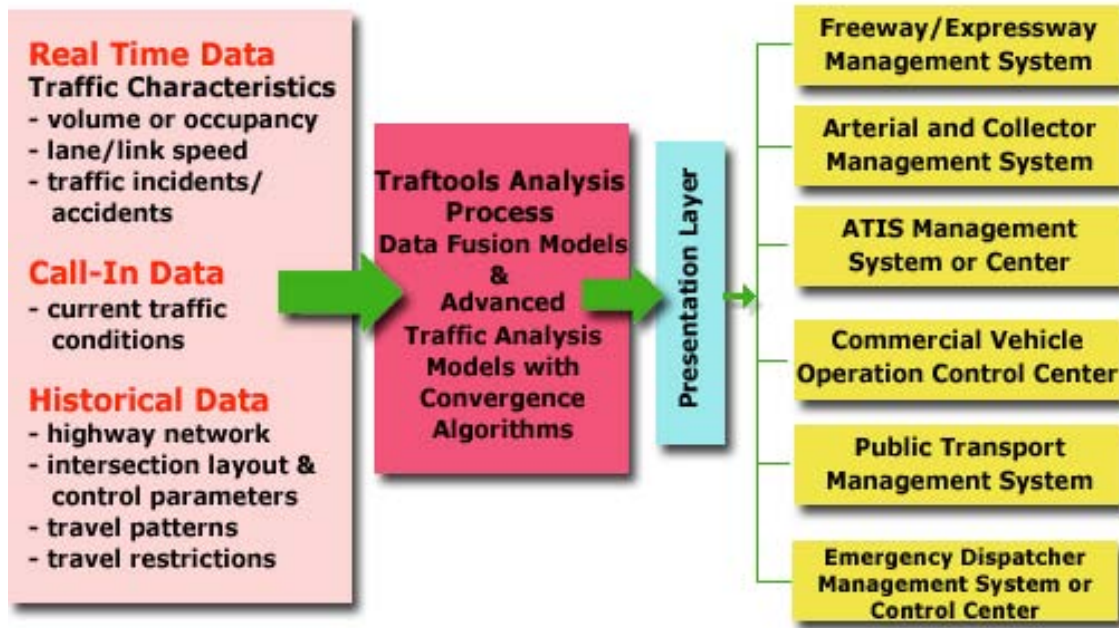


Figure 1 – The Traftools Real-Time Traffic Information Process

TIE™ incorporates three main types of traffic models: matrix estimation models, traffic assignment models, and macro simulation models. These models are described in greater detail in the sections that follow.

A. Matrix Estimation Models

In general, travel patterns in urban areas are represented using a trip table, also known as a trip matrix. The matrix describes the total number of trips originating from each zone to each of the others; this is usually called trip interchange. The process of estimation can be accomplished in a number of ways, but each starts with assumptions about group trip-making behavior and the way that this is influenced by external factors such as total trip ends, distance traveled, etc. TIE™ has not been developed to compute trip matrices from raw data, but rather begins with an existing trip matrix and improves it using an entropy-maximizing approach.

This entropy-maximizing approach was initially proposed by Willumsen in 1978 to derive a model to estimate trip matrices from traffic counts beginning with the old matrices. Mathematically, the problem can be written as:

$$\text{Maximize } S(T_{ij}/t_{ij}) = - \sum_{ij} (T_{ij} \log (T_{ij}/t_{ij}) - T_{ij} + t_{ij})$$

where: $S(T_{ij}/t_{ij})$ is the consistent value objective function

T_{ij} is the estimated number of trips between i and j

t_{ij} is the number of trips between i and j from the starting trip matrix

subject to:

$$V_a - \sum_{ij} T_{ij} P_{ij} = 0$$

where: V_a is the traffic volume for counted link a

P_{ij} is non-proportional assignment from origin i to destination j .

For each counted link a , such that:

$$T_{ij} \geq 0,$$

the volume constraint above replaces the trip-end and cost constraints of the gravity model deviation.

The use of Lagrangian methods permits the formal solution to this problem to be found as:

$$T_{ij} = t_{ij} \sum_a \exp(-\lambda_a P_{ij}^a) = t_{ij} \sum_a X_a^{P_{ij}^a}$$

where λ_a is the Lagrange multiplier corresponding to the traffic count constraints, and

$$X_a = \exp(-\lambda_a).$$

The entropy-maximizing formalism seeks to identify the most probable trip matrix consistent with the information available.

B. Traffic Assignment Models

Traffic assignment is the process of allocating vehicle trips from the matrices estimated above onto highway and public transit networks. The basic premise in traffic assignment is the assumption of a rational traveler, i.e. one who chooses the route that offers the least perceived (and anticipated) individual cost. A number of factors are thought to influence the choice of route when driving between two points, including travel time, distance, cost (fuel and other), congestion and queue length, type of roads, scenery, road work, accidents, and delays. In general, it is not practical to try to model all factors and therefore approximation is inevitable. The most common approximation is to consider only two factors: time and cost.

TIETM allows tree building based on both time and cost. Tree building is a process to find the shortest path (a set of links) between a point of origin and destination. There are many algorithms that may be used for tree building. TIETM adopted Dijkstra's algorithm, one of the most commonly used tree building algorithms found in many assignment models.

TIETM employs two assignment techniques for assigning vehicle trips onto a highway network and transit network simultaneously: Wardrop's equilibrium assignment and proportional stochastic assignment.

Equilibrium assignment attempts to approximate equilibrium conditions of traffic assuming that traffic arranges itself in congested networks in such a way that all routes between any O-D (origin-destination) pair have equal and minimal costs while all unused routes have

greater or equal costs. This is generally referred to as Wardrop's first principal. Wardrop also suggested the second principal as an alternative way of assigning traffic onto a network as follows: *Under equilibrium conditions, traffic should be arranged in congested networks in such a way that the average (or total) travel cost is minimized.*

Stochastic assignment emphasizes the variability in driver's perceptions of costs and the composite measure they seek to minimize (travel time, generalized costs). Stochastic methods need to consider second-best routes. Several methods have been proposed to incorporate these aspects, but only two have relatively widespread acceptance: simulation-based and proportional-based methods.

Transit assignment is somewhat more complicated than private vehicle assignment in that it requires important simplifying assumptions and computational requirements tend to be much heavier. The present version of TIE™ provides only for transit vehicle assignment without further consideration related to passenger trips. Transit assignment is useful when the mode of transit uses the same right-of-way as other vehicles. TIE™ allows for all classes of vehicle assignments to be carried out simultaneously, eliminating the need for a separate process devoted to transit alone.

C. Macro Simulation Models

Traffic flows generated by the assignment model are used as input for the simulation to calculate intersection delays. Intersection delays are subtracted from free-flow time along the links and compared with the assigned travel time. If the difference of the two travel times on any individual link is greater than an operator-configurable threshold percentage, the new link time (free flow time – delay) is put back into the assignment process for recalculating route choices and reassigning the vehicle trips again. This process improves both flow and travel time estimation along major links with critical intersections in the network. The procedure also ensures that the link flow is within the capacity of the link and that the rest of the flow will back up on that particular approach.

In modeling the actual movement of vehicles, there is usually a need to compromise between level of detail and execution time. Simulation of individual cars would yield unacceptably high run times for the production of real-time traffic information. Therefore, TIE™ employs macro simulation models with the following characteristics: the traffic stream is treated as a continuous fluid moving along the roadway while the microscopic-type model is adopted at intersections.

Simulation of the traffic stream along segments of the roadway between intersections is performed as follows:

- The traffic stream is treated as a continuous fluid; each individual vehicle is not identified.
- The road is modeled as links divided into several segments. The length of each segment is equal to the common unit cruise length for that particular class of links. The unit cruise length is the distance which one vehicle covers in one scan interval.

- At every scanning interval, a whole or a part of the existing volume is stored on segment k, and $V(k, t)$ is advanced to the next segment k+1. The volume of vehicles moving from segment k to segment k+1 is modeled as:

$$AF(k+1, t) = \text{Minimum} [C*NL, V(k, t-1), JD*UL*NL - V(k+1, t-1)]$$

where:

- AF(k+1, t) = Arrival flow at segment k+1 during the current scan
- C = Saturation flow rate
- NL = Number of lanes
- $V(k, t-1)$ = Existing volume at segment k on the last scan
- JD = Jam density
- UL = Unit length of segment
- $V(k+1, t-1)$ = Existing volume at segment k+1 on the last scan

Each segment has an upper limit for existing volume corresponding to $JD*UL*NL$. If the existing volume reaches the upper limit, the arrival flow is determined to be equal to zero.

Simulation of individual vehicle arrival is performed at intersections. At every scanning interval, flow profile at the intersection is accumulated. The probability of arrival can be obtained by the linear approximated function of the cumulative value as shown in Figure 2.

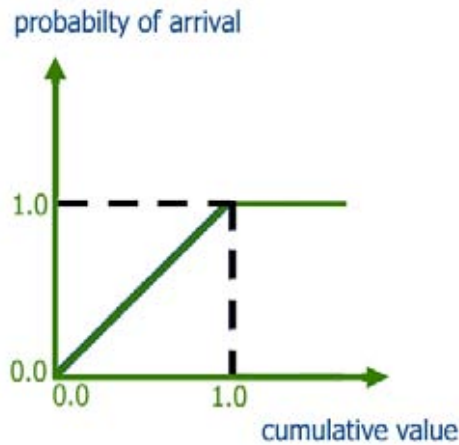


Figure 2 – Linear Approximated Function of Cumulative Arrival

Turning vehicles which cross lanes of oncoming traffic are also handled as individual vehicles. In case gap acceptance is specified, the vehicle is only able to turn if there is an acceptable gap in the opposing flow. The linear approximated gap acceptance function is shown in Figure 3.

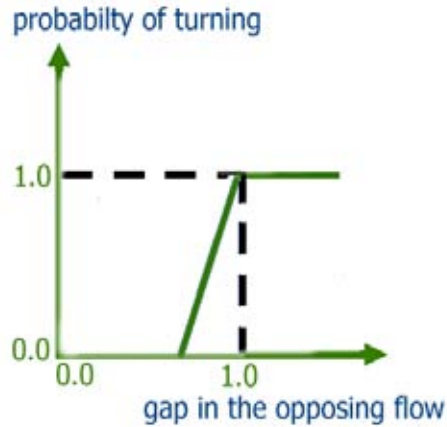


Figure 3 – Linear Approximated Gap Acceptance Function

The flow profile is divided into 5 regions as follows: free-flow region, deceleration region, congestion region, acceleration region, and saturation flow region. Each region represents states of traffic approaching, stopping, and leaving an intersection. Details of each state are beyond the scope of this paper.

4. Validation and Performance Check

Several outputs performed by the current version of the Engine have been compared with observed data for validation. Since data collection is very expensive, the results were compared with data available from a well-known intersection in Tokyo, Tatsumi-bashi, which experiences one of the heaviest levels of congestion throughout the city each day.

Data gathering was performed using 8 video cameras installed at various locations in order to monitor traffic patterns at the intersection. Figure 4 below shows the locations of detectors at the intersection where traffic volume was collected to be compared with the results from the video and the models. Observation data was gathered from 7:00 – 9:00 AM.

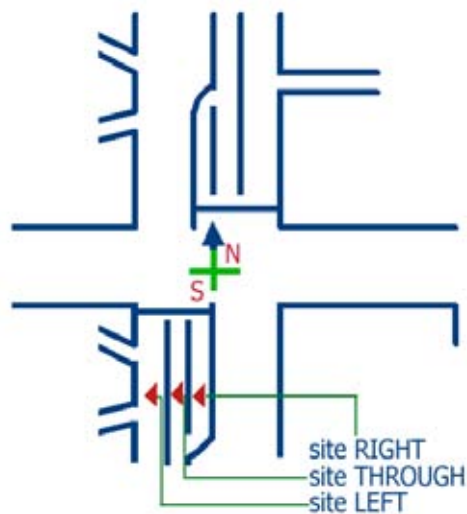


Figure 4 – Detector Locations for the South Approach

Figures 5a and 5b show the distribution of saturation flow rates along each of the approaches. The simulation output is in white and the observed is shaded.

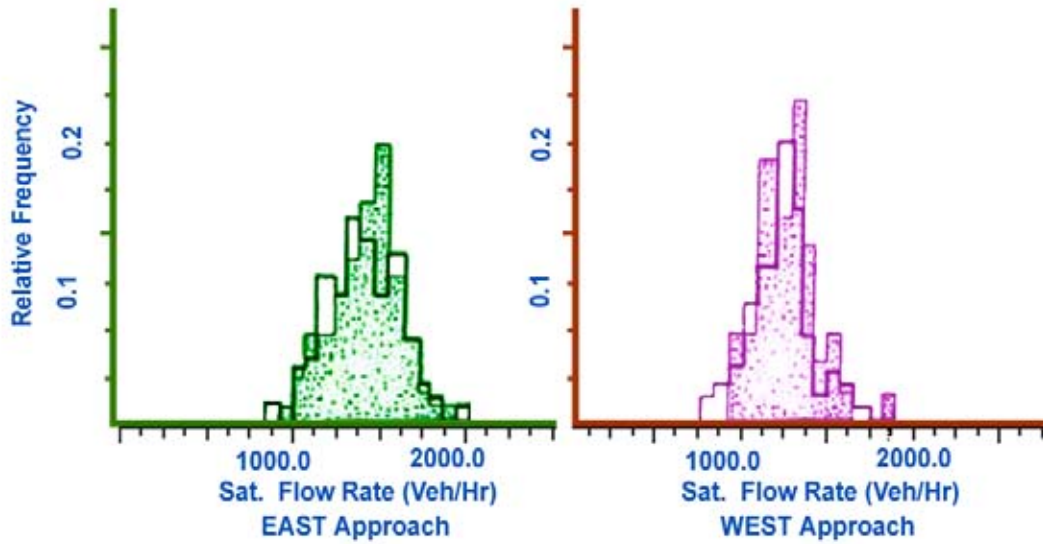


Figure 5a – East and West Approaches

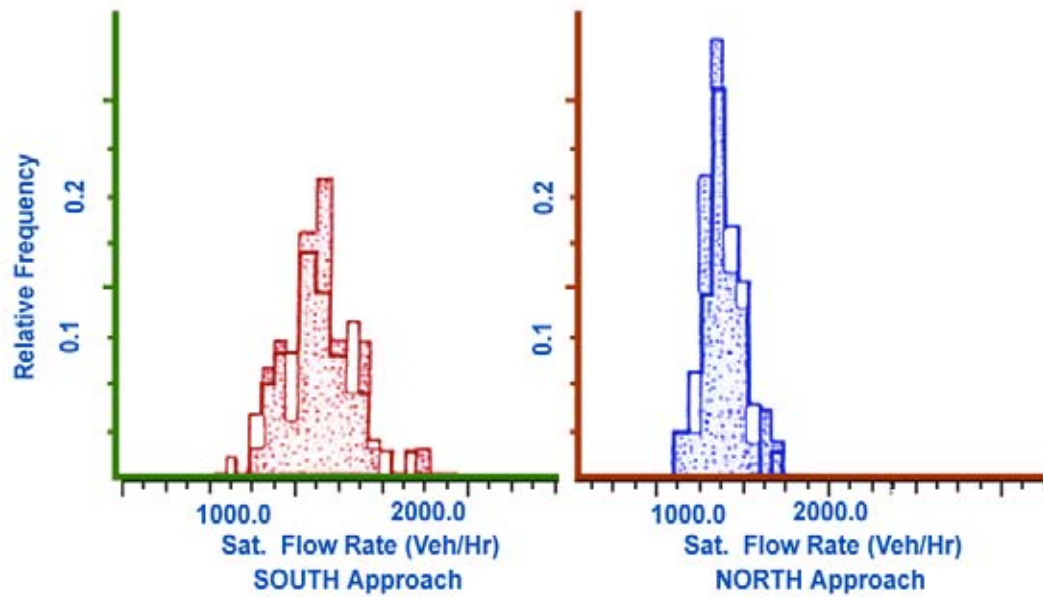


Figure 5b – South and North Approaches

Figure 6 shows time series of volume counts for different turning movements.

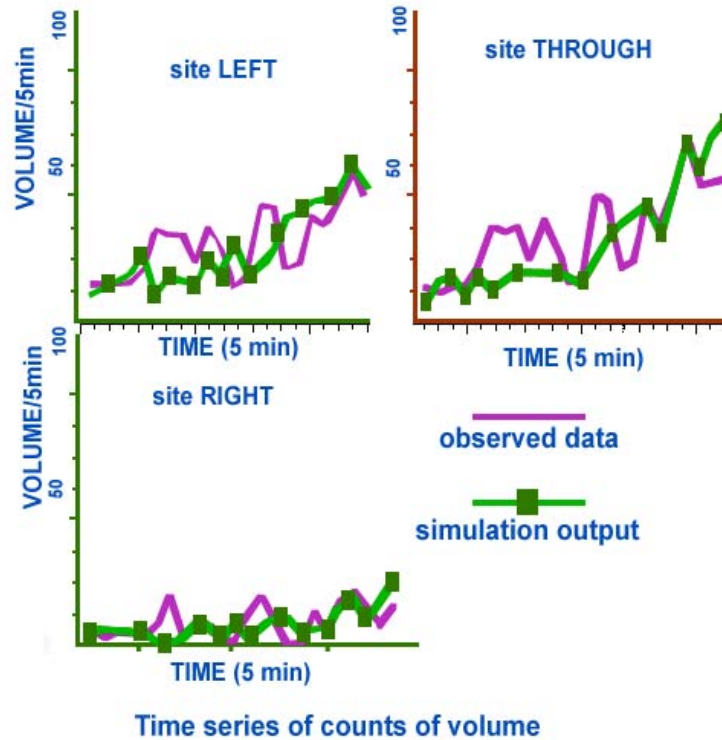


Figure 6 – Volume Counts over Time for Each Turning Movement

Figure 7 shows average occupancy vs. average queue and average delay from observed data and the simulation, respectively.

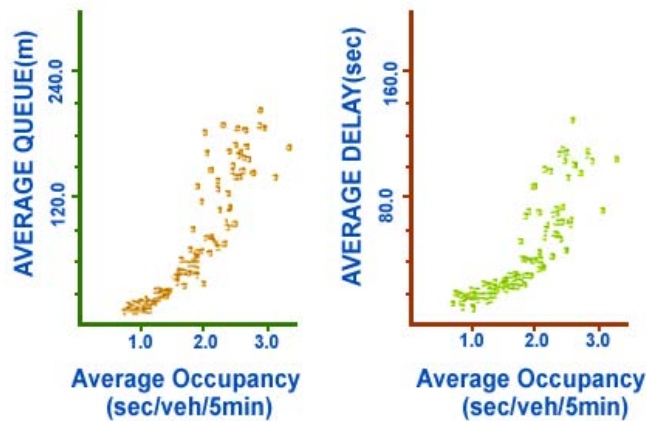


Figure 7 – Average Occupancy vs. Average Queue (Observed) and Average Delay (Simulated)

Figure 8 shows time series of occupancy data collected from traffic detectors for each of the turning movements compared with results from the simulation.

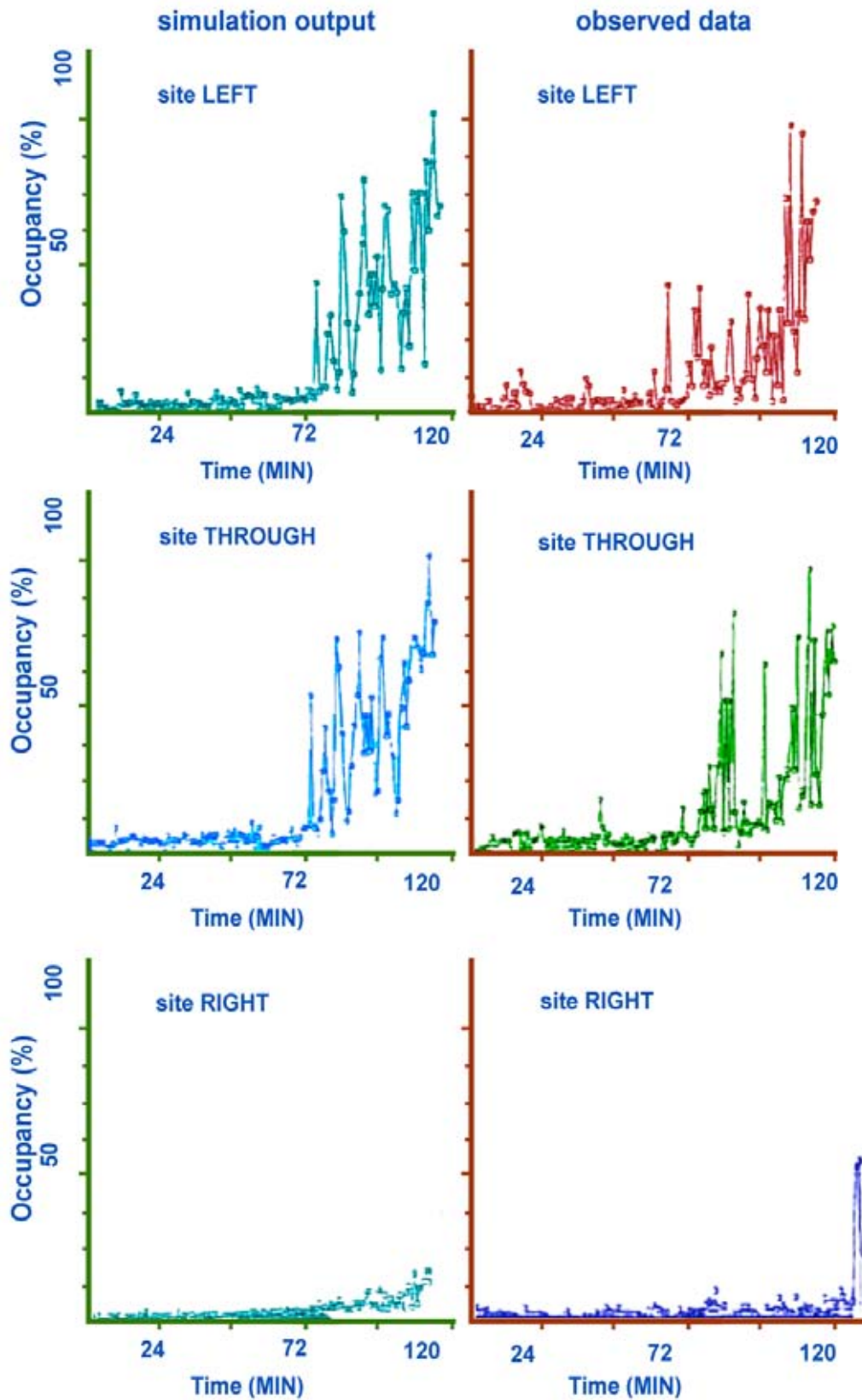


Figure 8 – Comparison of Simulated and Observed Occupancy for each Turning Movement

5. Presentation of Real-Time Traffic Information Using GIS-based Maps

There are significant advantages to deploying a GIS-based mapping solution for the presentation and dissemination of roadway and traffic condition information, some of which are outlined below.

- **Availability** – Most transportation agencies have already developed and use GIS-based maps for many purposes. Deploying GIS-based mapping solutions on the Internet to present roadway conditions and/or traffic information requires minimal extra investment. The existing GIS maps can be leveraged to reduce duplication of effort and development time. The time it takes to create and deploy the necessary GIS front-end presentation software may be considerably less than the time it would take to produce a similar proprietary static pictographic base map.
- **Integration** – In many cases, there can be seamless integration of GIS mapping products with other database systems already in use with a package such as ESRI's Spatial Database Engine, ArcSDE. For example, roadway management systems, sign and other control device inventory systems, network analysis models, bridge and roadway maintenance systems, and traffic safety analysis systems can all make use of and provide valuable information into a centralized GIS repository. The information sharing capabilities enabled by the implementation of a GIS database can both reduce administrative costs and effort, while at the same time making possible integrated systems and features that may have otherwise been prohibitive or altogether impossible.
- **Presentation** - Technology for presenting GIS-based maps via the Internet on a multitude of networked devices, including wireless PDAs, web-enabled cell phones, tablet PCs, and even in-vehicle systems is currently available and new software and devices continue to be developed. In addition, the standardization of the GIS platform and Internet protocols make GIS-based mapping solutions available to a wider audience and a larger number of devices with less problems and lower cost than proprietary systems developed for other types of maps.
- **Expansion** - Future expansion for the addition of more detailed information and new modes of dissemination is practically unlimited due to the open nature of the GIS platform and the number of companies, organizations, and individuals committed to the development of new GIS data and applications on a daily basis throughout the world.
- **Data Archiving** - Archiving of GIS data is made simpler through interfaces to many popular database products. Once again, the standardization of GIS technology leads to enhanced capabilities at reduced costs. Also, any engineer or scientist who has been involved in the study and planning of roadways and traffic control systems knows how important it is to have actual data to draw upon when creating and modifying his or her designs. While typically this data has been collected from the field on a case-by-case basis, there is no reason why a record of traffic data currently collected and produced cannot be archived for future use.

- **Long-Term Development** - Development of applications for use in the field of traffic operations such as Advanced Traffic Management Systems (ATMS), Advanced Rural Transportation Systems (ARTS), or Advanced Traveler Information Systems (ATIS) is much easier for both rural and urban areas as key information for study and planning is available from the archive management system and is already correlated with the GIS base map.
- **User Familiarity** - The latest civil and traffic engineers, geographic scientists, and planners are all familiar with and being trained on GIS-based products. The cost of continuing to train individuals on the operation and maintenance of proprietary systems far exceeds the amortized cost of the installation of a GIS-based solution. As those few experts on such proprietary systems leave their positions or head towards retirement, the costs of keeping these aging systems operational will only increase.
- **Cost Consideration** - The few disadvantages of using a GIS-based map, such as the one-time cost of switching from systems currently in use to GIS-based systems, and the increased processing power required as the amount of users and the size of GIS databases grows, are far outweighed by the benefits provided by a GIS-based solution. In the long-run, the cost of installing, operating, and maintaining a GIS will be much less expensive and more beneficial for everyone involved than continued use and development of proprietary systems destined for obsolescence.
- **GIS is the Glue** - One possible solution for integrating online database systems, data archiving and management systems, and data analysis and real-time advanced data manipulation models is GIS. GIS-based systems can provide highly customizable presentation and dissemination capabilities while still being relatively easy to use and at the same time having widespread availability and adoption. When compared with the alternative of developing, deploying, and maintaining one or more proprietary systems, some people might say that GIS is the only solution.
- **Traftools products** have been developed for and using GIS software from Environmental Systems Research Institute, Inc. (ESRI) – The GIS Software Leader. We and hundreds of other GIS-based software development companies are capable of developing custom and off-the-shelf solutions to meet the needs of GIS users and the transportation community-at-large. We believe that GIS-based mapping, presentation, archiving, and information management products are the best solution for intelligent traffic and transportation development now and long into the future.

6. Conclusion

Predictive real-time traffic information is useful for many purposes, including and especially for route guidance and traffic control. As with all information, one possible problem associated with predictive real-time traffic information is the level of accuracy which can be maintained. When considering levels of accuracy, the intended usage should always be taken into account. For certain applications such as for route guidance services and traffic impact studies for planned projects, the level of accuracy that can be provided by making comparisons of traffic conditions

between limited numbers of alternative routes should be acceptable. In contrast, traffic volume information for traffic control must be very accurate in order for the controller to provide reasonable control strategy and measures.

Traftools has designed the current version of the Traffic Information Engine (TIE)TM to provide real-time traffic information for the general public and for use in route guidance services, including fleet management applications. While TIETM relies on traditional traffic analysis and simulation models to produce this real-time traffic information, the integration with GIS has most certainly added value, made the process easier to set up and maintain, and generally been beneficial for the many reasons previously mentioned. In future releases of the Traffic Information Engine (TIE)TM, Traftools plans tighter GIS integration and the inclusion of special capabilities targeted at the traffic engineering and control communities.

7. References

- Phiu-Nual, K., & Koshi, M. (1989). Dynamic Macro Simulation Models for Complex Urban Street Network. *Control in Transportation System (1989) Proceedings of the 7th IFAC/IFIP/IFORS Conference, Tokyo, Japan.*
- Van Vliet, D. (1987). The Frank-Wolfe algorithm for equilibrium assignment as a variation of inequality. *Transportation Research, 21B(1)*, 87-9.
- Van Vliet, D., Bergman, T., & Schelters, W. (1987). Equilibrium Assignment with Multiple User Classes. *Proceeding 15th PTRC Summer Annual Meeting, University of Sussex, July 1987, England.*
- Wilson, A.G., & Kirby, M.J. (1980). *Mathematics for Geographers and Planners*. Oxford: Clarendon Press.
- Willumsen, L.G. (1984). Estimating time-dependent trip matrices from traffic counts. *Proceeding of the Ninth International Symposium on Transportation and Traffic Theory.*

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