HOMES: Highway Operation Monitoring and Evaluation System

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ABSTRACT

This work proposes high-performance critical visualization techniques for exploring real-time and historical traffic loop-detector data. Until recently, it has been difficult to discover trends, identify patterns, or locate abnormalities within the massive collection of traffic data. Many of the current visualization techniques do not scale to large data sets and are not practical for interactive visualization. We have developed an effective visualization system, Highway Operation Monitoring and Evaluation System (HOMES), for observing the summarization of spatiotemporal patterns and trends in traffic data. HOMES is designed for browsing the spatial-temporal dimension hierarchy via integrated roll-up and drill-down operations. The identified traffic patterns and rules can assist decision-making for transportation managers, establish traffic models for researchers and planners, and allow travelers to select commuting routes.

Categories and Subject Descriptors

H.4 [**Information Systems Applications**]: Decision Support

General Terms

Measurement, Performance

Keywords

Data Streams, Visualization, Intelligent Transportation System

1. INTRODUCTION

Increasing population, rising fuel costs, and stricter environmental policies have all contributed to the greater demand for improved roadway capacity and efficiency. A key component in improving the efficiency of the roadway network is the availability of an advanced traffic information system to provide real-time monitoring and long-term evaluation of the roadway conditions. To that endeavor, we have developed the Highway Operation Monitoring and Evaluation System (HOMES), a traffic visualization system that allows for browsing the spatiotemporal dimension hierarchy via integrated data cube operations. The Virginia Department of Transportation (VDOT) currently utilizes HOMES to monitor traffic incidents, analyze roadway behaviors, develop operation strategies, and verify highway designs. In general, HOMES can identify traffic patterns, rules, and anomalies to achieve the following benefits: efficient roadway designs; objective evaluation metrics of traffic policies; improved management of operations and emergent events; and better utilization of the roadway network.

Currently, HOMES monitors highways I-66 and I-395 within the Washington Metropolitan Area. It collects streaming information (arrival rate = 1 observation/sensor/min) from approximately 850 radar sensors and loop detectors. An important challenge in the development of HOMES is the provision of real-time query processing for both current and historical data under various cube operations. To address this issue, HOMES employs a spatial data warehouse approach as the underlying traffic data management strategy [2]. Fast cube-based query response times are achieved by maintaining concurrent sets of aggregated and non-aggregated sensor information. Quick traffic data updates are accomplished by an incremental approach for computing the updated aggregate and non-aggregate representations of the traffic data streams.

2. VISUALIZATION OVERVIEW

A traffic measure (e.g., speed) is observed at a particular time and space. The following describes the supported types of traffic measure and its associated time/space aggregations:

Traffic measure – The core traffic measures provided by the detectors are speed (avg. vehicle velocity), volume (# of vehicles), and occupancy (ratio of time vehicle is detected). The derived measures are travel time, travel time index (ratio of current to historical travel time - TTAi), flow (# of vehicles detected per hour), vehicle miles traveled (total miles traveled by all vehicles), vehicle hours traveled (total hours accumulated by all vehicles), and delay (difference of current travel time and ideal travel time).

Time – Time is aggregated into time of day (time point or time range), T_{TD}, and day of week (Monday to Sunday), T_{DW}.

Space – Spatial entities are hierarchically categorized into detectors, S_D, station (a set of spatially continuous detectors), S_{ST}, link (set of spatially continuous stations), S_L, and section (set of spatially continuous links), S_{SE}.

For each traffic measure, associated visualizations are given from several elements of the pair-wise combination set of T and S aggregation hierarchy. For example, a contour plot ($T_{TD}S_L$) can be shown for all sets of available links in a highway for a given time range. Hence, roll-up and drill-down operations are supported by navigating the various hierarchies of the time and space dimensions. Figure 1 shows the supported visualization dimension hierarchy of HOMES.
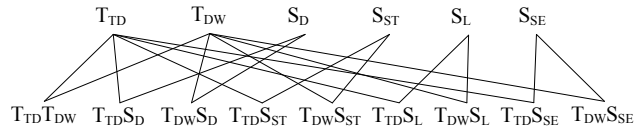

Figure 1. HOMES visualization dimension hierarchy. Each node represents a supported visualization.

3. CASE STUDY: INCIDENT MONITORING AND ANALYSIS

In this section, we demonstrate the use of HOMES visualization system for detecting, monitoring, and evaluating a traffic incident that occurred at I-66 westbound on February 5, 2008 10:50 AM. The incident was an overturned vehicle that resulted in a blockage of the left lane.

| **Figure 2. S_L map of I-66 link-level travel time index (TTAi) at 10:50 AM on Feb 5, 2008. The black box shows the incident region.** | **Figure 3. S_D map of detector speeds (MPH) at 10:50 AM on Feb 5, 2008. The black box shows the incident region.** |

Incident detection: Figure 2 (left) provides the S_L map snapshot of I-66 on Feb 5, 2008 at 10:50 AM. The area inside the black rectangle is the region of traffic incident. Under normal circumstance, the link within the rectangle would exhibit a travel time index (TTAi) of 1. However, the exhibited link travel time is about 50% more than usual (TTAi > 1.5) which would indicate a potential incident to the traffic operators. Figure 3 gives the drill-down detector view (S_D) of the incident link. Certain incidents can exhibit localized congestion within a particular lane, however, the dramatic speed drops of all the surrounding lanes imply that the observed situation is more severe. In

short, these multiple views allow traffic operators to rapidly detect and provide quick evaluations of a traffic incident.

Monitoring incident recovery: As the incident progresses, traffic operators can monitor the real-time status of the affected roadway segment. This ability allows the operators to dynamically assess the effectiveness of its recovery effort and invoke necessary protocols to minimize the total recovery time. Figure 4 provides the T_{TD} speed and travel time plots of the incident link compared to its average value of the past two weeks. At around 11:50 AM, the speed begins to rise indicating the first measurable effects of the incident recovery process. Traffic models employing flow theory can be applied to this data sample to extrapolate the amount of time for which traffic will resume to normal speed [1]. If the observed recovery starting point occurred at a much later time, then the likelihood of the congestion coinciding with the evening rush hour is increased. At that point the traffic operator may invoke a protocol calling for more on-site emergency response personnel. An additional benefit provided by the T_{TD} visualization is that it allows the users to precisely determine the incident time. Although the incident was reported to have occurred at 10:50 AM, the graph indicates that it actually occurred 20 minutes earlier at 10:30 AM.
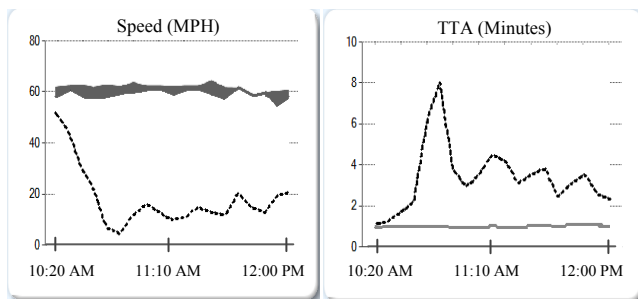

Figure 4. T_{TD} **speed plot (left) and** T_{TD} **travel time plot (right) of incident link from 10:20 AM to 12:00 PM. Dotted line is the current traffic and solid line is the avg. traffic for the past 2 weeks.**

Another important task is to monitor the effects of the incident on its neighboring links and lanes. Figure 5 gives the $T_{TD}S_L$ and $T_{TD}S_D$ plots of the adjacent links and detectors. This type of information gives a broader picture of the incident's impact and provides traffic operators with concrete actionable information to minimize the incident recovery time (e.g., activating ramp meters to reduce inbound traffic flow).
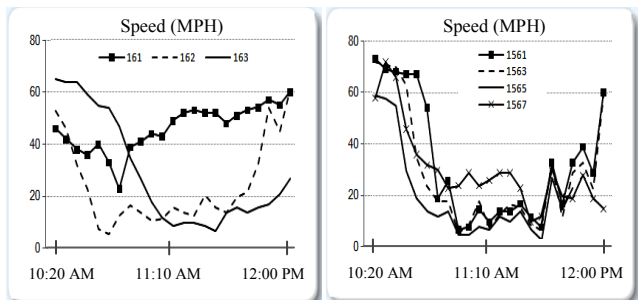

Figure 5. $T_{TD}S_L$ **speed plot (left) of incident link (162) and its adjacent neighbors.** $T_{TD}S_D$ **speed plot (right) incident lane and its neighbors.**

Post-incident analysis: One critical question that is posed by traffic engineers and planners is the following, "What was the *total* impact and cost of the incident?" The cost is commonly derived from the total observed delay which can be converted to a dollar measure of productivity loss. Figure 4 provides a part of that answer by displaying the total delay incurred at a small and localized link region. To analyze the impact of the incident for the total highway section, HOMES provides $T_{TD}S_{ST}$ contour plots (Figure 6) which gives the overall impact to vehicular speed for the entire span of I-66 westbound. The *x*-axis gives the time, *y*-axis represents the milepost location, and color indicates the speed values. Compared to a non-

incident day (previous day), the impact of the traffic can be seen to affect approximately 10 miles of I-66 (from mileposts 60 to 70) for the period of 2.5 hours. The exact speed values can be obtained by invoking the HOMES data export function. With this data, the cost of the productivity loss can be more accurately computed.
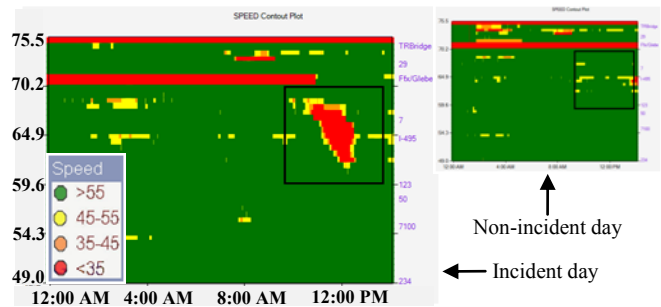

Figure 6. $T_{TD}S_{ST}$ **speed contour plots for the entire stretch of I-66 between 12:00 AM 2:00 PM. Black box indicates incident region.**

Performing a drill down operation on the contour plot by taking the vertical cross-sections of all highways at times 11:20 AM and 12:00 PM produces the plots in Figure 7. In this figure, one can observe with greater resolution the effects of the incident on the spatial dimension at specific snapshots of time.
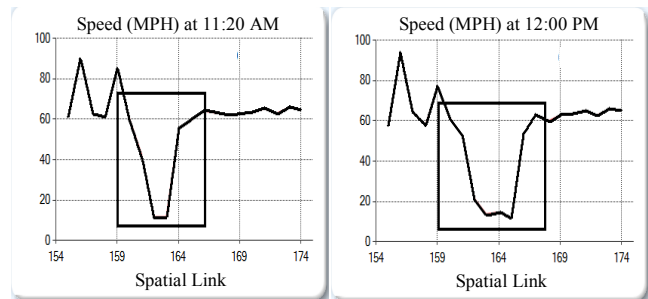

Figure 7. S_L **speed plots of I-66 at 11:20 AM (left) and 12:00 PM (right). Black box indicates incident region.**

4. SUMMARY

Visualization has shown to be an important tool for identifying patterns, trends, and anomalies in massive spatial data sets. HOMES is an attempt to develop visualization techniques for monitoring and analyzing traffic data. HOMES enables a comprehensive analysis of highway conditions and patterns by implementing high-performance cube operations coupled with a extensive set of visualizations. As exemplified by the case study, HOMES can facilitate VDOT engineers and operators by reducing their response time to an emergent event, providing real-time feedback of their recovery efforts, and quantifying their overall performance. Furthermore, HOMES' visualization components support short/long-term analysis to improve traffic operation strategies, validate highway designs, and enhance utilization of the roadway network. The provided visualization components alleviate much of the time-consuming and manual tasks of knowledge discovery, and thus promoting the effective and efficient use of the transportation data.

5. REFERENCES

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