Cubeview: A Web-based Visualization Tool for Intelligent Transportation Systems

http://spatial.nvc.cs.vt.edu/traffic

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1. Introduction

Transportation policy affects a diverse stakeholder group that depends on policymakers to provide a network within which they can achieve their travel objectives. Stakeholders include individuals, households and purveyors of goods and services with varying values of time, income, and travel expectations. The combined and conflicting activities of transportation network stakeholders contribute to the creation of traffic congestion. Excessive traffic congestion adversely affects individual drivers, the movement of goods, provision of services, and ultimately the economic vitality of a region. In their annual assessment of urban mobility, Schrank and Lomax (2003) indicate that congestion has grown in areas of every size, and congestion costs are increasing. Wachs (2003) argues that highway congestion will continue to grow because traffic volumes are growing faster than highway-related revenues, and higher proportions of state transportation budgets must be spent on maintenance, operations and rehabilitation instead of new roadway capacity. To optimize stakeholder travel objectives, tools and techniques are needed to detect trends, patterns and abnormalities in traffic flow. These tools and methods must provide real-time data to support management decisions. One such method, data visualization, is expected to play an important role in extracting such useful information that may be used by network managers.

Cubeview offers a high-performance critical visualization technique that may be used for exploring real-time and historical loop-detector data. The technique scales to large data sets and is practical for interactive visualization. Using Cubeview, it is convenient to observe the summarization of spatiotemporal patterns and trends in loop-detector data. Cubeview is designed for browsing the spatial-temporal dimension hierarchy via integrated roll-up and drill-down operations. It supports data visualization in a web-based environment without the requirement of a Java runtime environment. Users can conveniently access the system via a web browser, thus facilitating the utilization of transportation information. The identified traffic patterns and rules can assist decision-making for transportation managers, establish traffic models for researchers and planners, and allow commuters to select commuting routes. Traffic data for I-66 in Northern Virginia is used to demonstrate the functionalities of Cubeview.

2. Concept and System Architecture

The concept of the data cube is the engine behind Cubeview. A data cube is used to generate the union of a set of alpha-numeric summary tables corresponding to a given hierarchy. Based on the concept of a data cube, Cubeview organizes the album of generated visualization using a given hierarchy to support browsing via roll-up, drill-down, and other operations on an aggregation hierarchy. For traffic data, the dimensions are time and space and the measures are volume, occupancy, and speed. Dimensions are hierarchical by nature. The time dimension T can be grouped into "hour", "date", "month" or "year", forming a lattice structure. Similarly, the space dimension S can be grouped into "station", "county", "highway", or "region." Given the dimensions and hierarchy, the measures can be aggregated in different visual formats.

Figure 1 illustrates the dimension hierarchy of Cubeview, where T_{TD} is the time of day, T_{DW} is the day of the week, and S is a station or group of stations. Each node in Figure 1 is a visualization style. For example, the ST_{TD} node represents the daily traffic volume of one station. Figure 2 provides an example of nodes in the Cubeview system. The three dimensions are Station (S), Time of Day (T_{TD}), and Day of Week (T_{DW}), and the three pictures correspond to the three 2-D nodes, Time of Day vs. Day of Week ($T_{TD}T_{DW}$), Day of Week vs. Station ($T_{DW}S$), and Station–Time of Day (ST_{TD}).
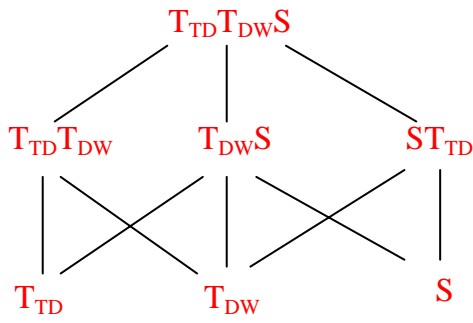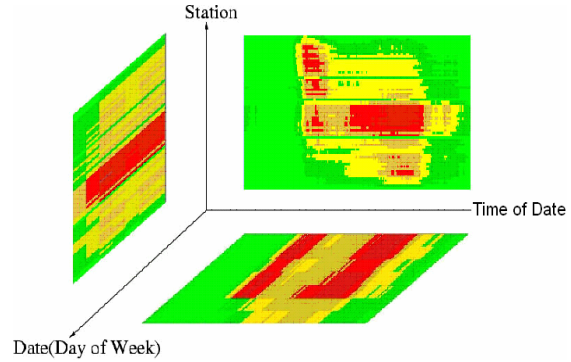
Figure 1: Dimension hierarchy of Cubeview.   Figure 2: Traffic dimensions.

The traffic data used in Cubeview is transmitted from the Smart Travel Center of the VDOT Northern Virginia District, which monitors sensor network measurements from the highway systems, including I-66, I-395, I-95, and I-495. Figure 3 shows all the stations used in the current system, which includes 356 detectors and 96 stations.

Figure 3: Locations of all detectors/stations on I-66 in the Fairfax county region.

3. System Demonstration

Cubeview can dynamically display both real-time and historical traffic flow, such as volume, occupancy, and speed, upon requests. Six different kinds of visualization components are illustrated as follows:

T_{TD} **(Time of Day)**: Figure 4 (a) shows the traffic flow at eastbound station 121, where I-66 crosses Route 28, on Tuesday Nov 2nd, 2004. This figure shows a distinct morning rush hour pattern between 5AM and 10AM, where volume is greater than 300 vehicle per five minutes. Figure 4 (b) shows the traffic flow at westbound station 112, between Route 28 and Route 29, on the same date. This figure shows a clear evening rush hour pattern between 4PM and 6AM, where speeds is drop to below 25mph.

Figure 4(c) shows the traffic flow at eastbound station 281, located between Chain Bride Road and Nutley Street, during Monday November 26th, 2004 to Sunday November 28th, 2004, where Thursday November 25th was Thanksgiving holiday. This figure shows a regular morning rush hour pattern during Monday to Wednesday, and reduced traffic flow from Thursday to Sunday. Figure 4(d) shows the traffic flow at westbound station 521, located between Capital Beltway (I-495) and Nutley Street, during Monday December 20th, 2004 to Sunday December 26th, 2004, where Saturday December 25th was Christmas Holiday. This figure shows a regular evening rush hour pattern during Monday to Wednesday, and reduced traffic flow from Friday to Sunday. It's interesting to observe the congestion between noon and 4PM on

Thursday December 23rd, where speed is drop to below 25mph, even the traffic volume is not high. Notice there is a malfunctioned measurement at 8:50AM on Monday December 20, where volume is greater than 1000 vehicle per five minutes.

Figure 4(e) shows the traffic flow at eastbound station 621(milepost 58.3), located between Route 50 and Lee Jackson Highway, during Monday November 1st to Tuesday November 30th, 2004. The recurrent morning rush hour pattern with reduced speed during Monday to Friday can be clearly observed. Figure 4(f) shows the traffic flow at westbound station 112, located between Route 28(Sully Road) and Route 29 (Lee Highway), during the same period. This figure shows a recurrent weekly evening rush hour pattern from Monday to Friday.
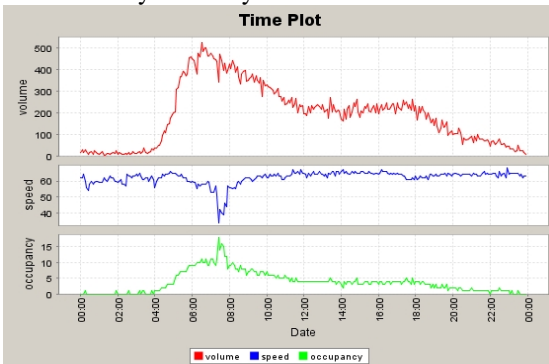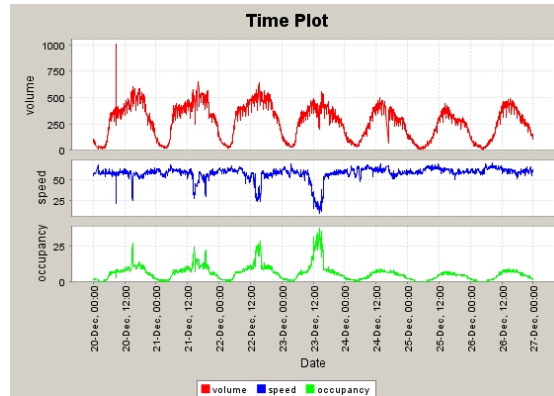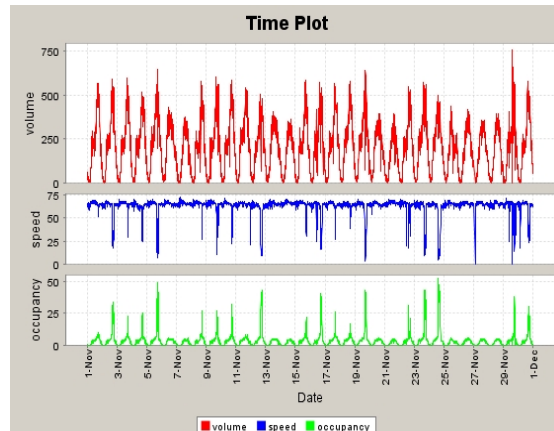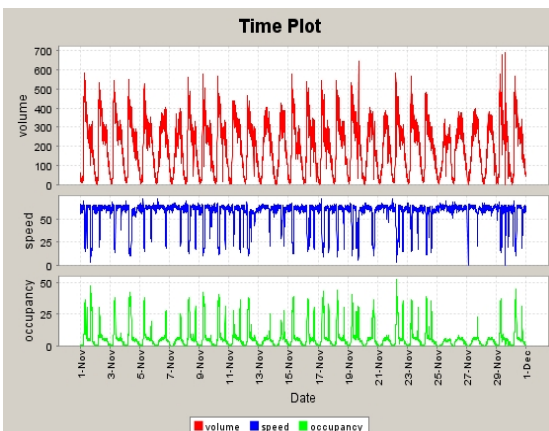

(b) Westbound Station 112 on Tue Nov 2nd, 2004
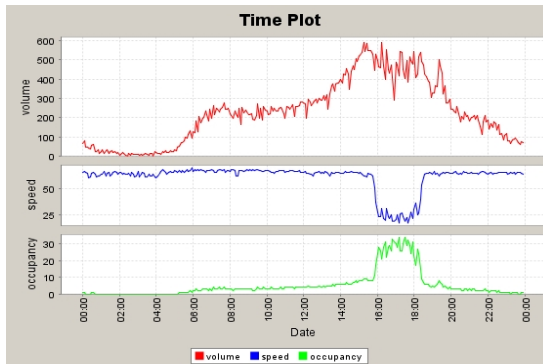
(a) Eastbound Station 121 during Nov 2nd, 2004
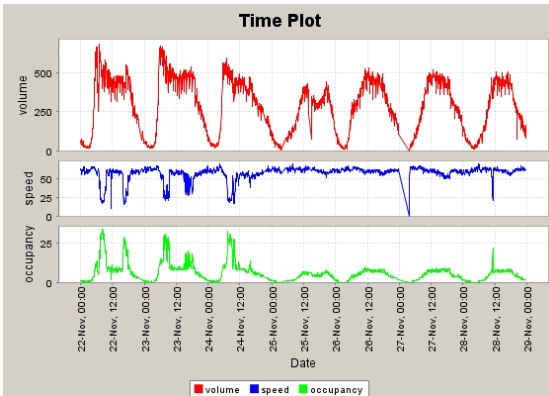

(c) Eastbound Station 281, November 22th-28th, 04'

(d) Westbound Station 521, Dec 20th-26th, 04'

$\mathbf{T_{DW}}$ **(Day of Week/Month)**: Figure 5(a) shows the traffic flow at eastbound station 121 at 8:30AM for March 2004. Figure 5 (b) is the traffic flow at westbound station 112 at 6:00PM for March 2004. Figures 5 (a) and (b) show a recurrent weekly pattern, where the traffic volume on Saturdays and Sundays is lower than on weekdays.
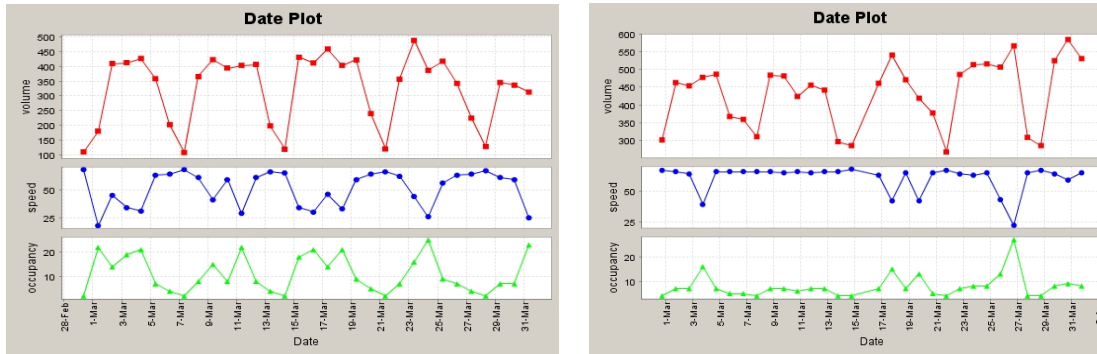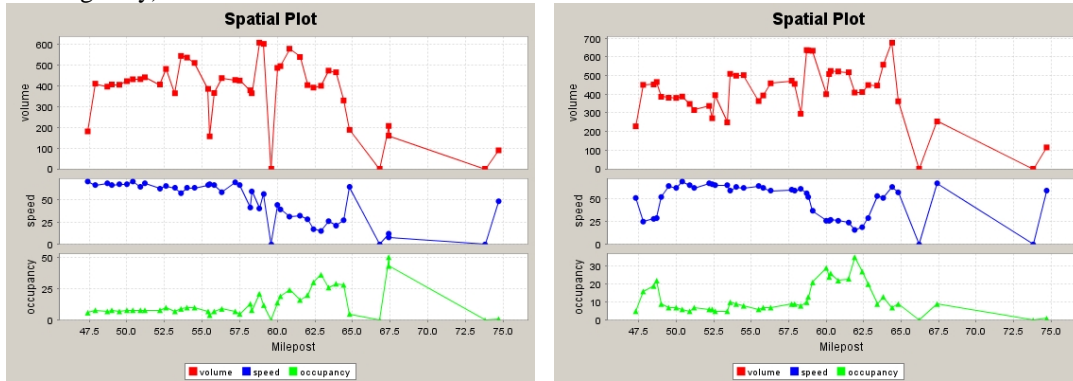

(a) Eastbound Station 121 at 8:30AM.   (b) Westbound Station 112 at 6:00PM.
Figure 5: $\mathbf{T_{DW}}$ representation of eastbound and westbound traffic stations in March 2004.

S (Highway Stations): Figure 6(a) shows the traffic flows for all the eastbound stations at 8:30AM on Tuesday Oct 26th, 2004. As can be seen, the occupancy is relatively higher and speed is lower between mileposts 60 and 65. The stations at mileposts 59, 67, and 74 malfunctioned, generating zero values. Figure 6(b) shows the traffic flows for all the westbound stations at 6:00PM on Tuesday Oct 26th, 2004. Here, the occupancy is relatively higher and speed is lower between milepost 59 (Chain Bridge Road) and milepost 63 (Capital Beltway I-495), and between milepost 48 (Route 234, Sudley Road) and milepost 49 (Route 29, Lee Highway).

(a) All eastbound stations at 8:30AM.   (b) All westbound stations at 6:00PM.
Figure 6: $\mathbf{S_{highway}}$ representation on Wednesday Nov 3rd, 2004.

$\mathbf{ST_{TD}}$ **(Highway stations vs. Time of Day)**: Figure 7(a), 7(b), and 7(c) correspond to the node $\mathbf{ST_{TD}}$ for volume, speed, and occupancy, respectively. Figure 7 shows the traffic flow for all eastbound stations on Saturday, Nov 6th, 2004. We can observe a distinct incident pattern between mileposts 59 and 63 during the period of 9:30AM to 10:15AM. The upside-down triangles visible in Figure 7(b) and Figure 7(c) represent the propagation congestion patterns due to this incident as they affect subsequent stations.
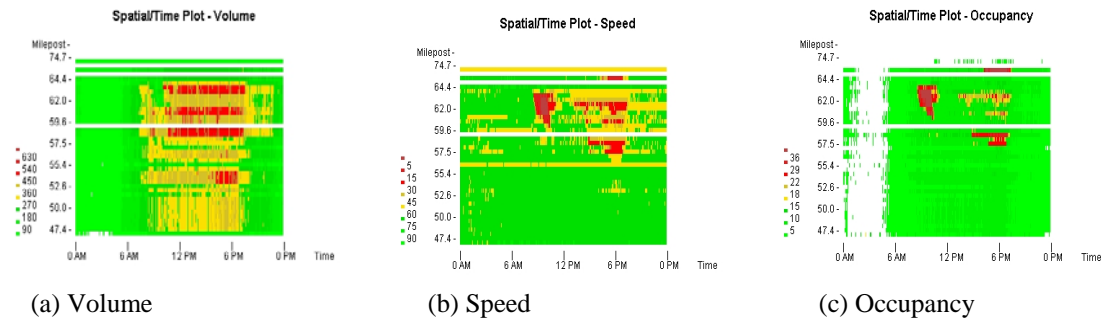
(a) Volume   (b) Speed   (c) Occupancy

Figure 7: ST_{TD} representation of traffic flow at all eastbound stations on Saturday Nov 6th, 2004.

Figure 8 shows the traffic flows for all the westbound stations on Wednesday Nov 3rd, 2004. The evening rush hour pattern from 2PM to 7PM can clearly be observed in Figure 8(a). Two triangles can be identified in Figures 8(b) and 8(c). These are the recurrent evening rush hour congestion patterns at Vienna area between Capital Beltway (I-495) and Nutley Street, and at Manassas area between Sully Road (Centreville Road) and Sudley Road during the period 1PM to 5PM.
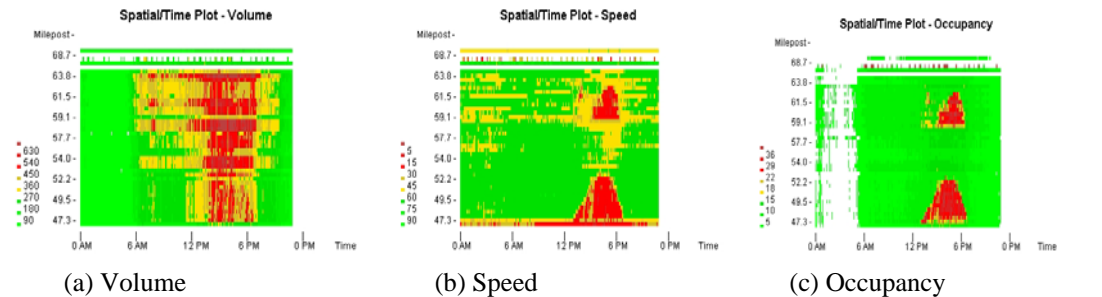
(a) Volume   (b) Speed   (c) Occupancy

Figure 8: ST_{TD} representation of all westbound stations on Wednesday Nov 3rd, 2004.

$T_{TD}T_{DW}$ (**Time of Day vs. Day of Week**): Figures 9(a) and 9(b) show the average Sunday and Tuesday traffic flow at eastbound station 121, during the period Oct 1st to Oct 31th, 2004. The system generates 7 charts corresponding to each day of the week. Figure 9(a) shows there is higher volume and occupancy between 2PM and 6PM on an average Sunday. Figure 9(b) shows that there is an extraordinary high volume and occupancy, and lower speed during 5AM to 8AM time period on an average Tuesday.

(a) Average Sunday pattern   (b) Average Tuesday pattern

Figure 9: $T_{TD}T_{DW}$ representation of eastbound station 121 during Oct 1st to Oct 31th, 2004.

Figure 10(a), 10(b), and 10(c) correspond to the node $\mathbf{T_{TD}T_{DW}}$ for volume, speed, and occupancy, respectively, for the average weekly traffic flow at eastbound station 361 (Nutley Street - Capital Beltway), during the period Oct 1st to Oct 31st, 2004. Figure 10(a) shows there is higher volume between 8AM and 6:30PM on an average Saturday, and higher volume between 11AM and 6:00PM on an average Sunday. Figure 10(b) and 10(c) shows there is lower speed and higher occupancy between 6AM and 9AM on average weekdays.

(a) Volume   (b) Speed   (c) Occupancy

Figure 10: $\mathbf{T_{TD}T_{DW}}$ representation of eastbound station 361 during Oct 1st to Oct 31st, 2004.

Figure 11(a), 11(b), and 11(c) correspond to the node $\mathbf{T_{TD}T_{DW}}$ for volume, speed, and occupancy, respectively, for the average weekly traffic at westbound station 62 (Lee Highway - Sudley Road), during the period December 1st to December 31st, 2004. Figure 11(a) shows there is higher volume between 3PM and 6:30PM on average weekdays. Figure 11(b) and 11(c) shows there is lower speed and higher occupancy between 3:30PM and 7:00PM on average weekdays. In Figure 10(b), it's interesting to observe that speed is drop to below 55mph starting from noon to 7:00PM on average Friday.


(a) Volume   (b) Speed   (c) Occupancy

Figure 11: $\mathbf{T_{TD}T_{DW}}$ representation of eastbound station 62 during Dec 1st to Dec 31st, 2004.

$\mathbf{ST_{DW}}$ **(Highway Stations vs. Day of Week)**: Figure 12(a) and 12(b) show the average Sunday and Tuesday traffic flow for all westbound stations at 6:00PM, during the period Oct 1st to Oct 31st, 2004. The system generates 7 charts, corresponding to each day of the week. Figure 12(a) shows a smooth traffic pattern on an average Sunday, whereas Figure 12(b) shows a reduced speed between milepost 59.1 (Chain Bridge Road) and milepost 63.4 (Nutley Street), on an average Tuesday.

(a) Average Sunday pattern   (b) Average Tuesday pattern

Figure 12: ST_{DW} representation of all westbound stations at 6:00PM from Oct 1st to Oct 31th, 2004.

Figure 13(a) and 13(b) correspond to the node ST_{DW} for speed and occupancy, respectively, for all westbound stations at 5:30PM, during the period Oct 1st to Oct 31st, 2004. As can be observed from both figures, there is high occupancy and low speed at Vienna area between milepost 59.1 (Chain Bridge Road) and milepost 63.4 (Nutley Street) during average Monday to Thursday at 5:30PM. On an average Friday, however, there is high occupancy and low speed at Manassas area between milepost 52.4 (Lee Highway) and milepost 47.3 (Sudley road) at 5:30PM.
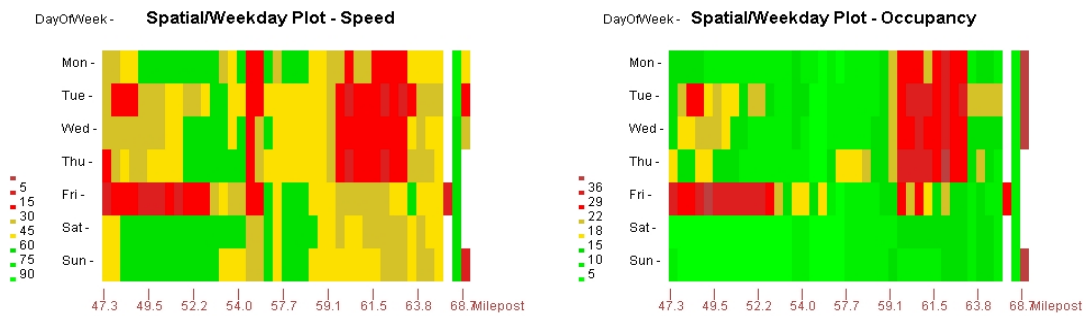
          (a) Speed   (b) Occupancy

Figure 13: ST_{DW} representation of all westbound stations at 5:30PM from Oct 1st to Oct 31th, 2004.

4. Transportation Policy Implications

Downs (2004) argues that the addition of road capacity is totally impractical and prohibitively expensive. He asserts that, "Governments would have to widen all major commuting roads by demolishing millions of buildings, cutting down trees, and turning most of every metropolitan region into a giant concrete slab". If Downs' assessment is accurate then transportation policymakers must mitigate traffic congestion by other means, whether via travel demand management strategies or by using information derived from technological developments, such as Cubeview. However, will the use of Cubeview or other data visualization techniques reduce congestion? If so, will decreases in congestion militate against the use of transit or other transport modes? That is, will "smoothing out" commutes (based on an enhanced understanding of trends and patterns) produce latent demand (i.e., attract commuters to formerly congested routes)? Will smoothing out commutes promote longer trips (or sprawl)? Will transportation officials armed with new information regarding trends and patterns inadvertently adopt policies that favor one societal group over another? That is, will using Cubeview or other data visualization techniques result in a Pareto improvement (a change that makes one better off without making any other worse off)? Additionally, with respect to social equity, will those without access to web-based tools that may be used for route choice decisions be relegated to congested travel lanes because they lack information to make alternate route choices? Finally, from an institutional perspective, is there the will to alter land use regulations to permanently effect changes in traffic patterns and trends?

5. Conclusion

The concepts of visualization have proven to be highly useful for identifying patterns in large spatial data sets. Cubeview is an attempt to develop these techniques and apply them to analyze traffic data. These interactive visualization techniques make the knowledge discovery process much less burdensome, and thus facilitate the usage of the transportation data. In addition to visualization, data mining techniques can be employed for data analysis and filtration. One such technique is the identification of outliers, which plays an important role in automatically recognizing abnormal situations and emergency congestions. The prototype developed for the Cubeview system now provides an analysis in 2D, an effort is currently underway to develop 3D representation. Such a representation will provide users with an immersive experience. Future adaptations of this work will address issues in predicting patterns based on current stream and historical trends, and supporting adaptive user interfaces based on users' expertise and requirements. (Cubeview is available at: http://spatial.nvc.cs.vt.edu/traffic/)

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