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Data Visualization as a Tool for Improved Decision Making within Transit Agencies

by

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16. ABSTRACT

TriMet, the regional transit provider in the Portland, OR, area has been a leader in bus transit performance monitoring using data collected via automatic vehicle location and automatic passenger counter technologies. This information is collected and archived for offline analysis of transit operations. Performance monitoring at TriMet is structured to address both short and longer term business needs. Two general information dissemination methods are employed: 1) highly interactive, custom software applications allowing agency personnel to query and display information needed for the day-to-day management of operations and 2) static performance reports generated on regular bases (e.g., quarterly, annually) which provide a complete picture of the transit system at multiple summary levels as part of a longer term performance monitoring and evaluation program. While the amount of work undertaken in the area of performance measurement has been considerable, much of the information is not being presently utilized due to the sheer quantity of information available. Efforts to incorporate new data visualization techniques will do much to assist with the identification of operational problems as well as provide insight into potential solutions.

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Abstract

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1. Introduction

TriMet, the regional transit provider in the Portland, OR, area has been a leader in bus transit performance monitoring using data collected via automatic vehicle location (AVL) and automatic passenger counter (APC) technologies. A vast amount of information is collected and archived for offline analysis of transit operations. This information is summarized on regular bases in the form of performance reports that help inform agency personnel about the status of various parts of the transit system across multiple spatial and temporal dimensions. The agency has also implemented several dynamic transit performance monitoring applications allowing for the rapid retrieval of transit performance information needed to support daily operations.

Performance monitoring capabilities at TriMet greatly expanded in 2001— following a “shaking out” period related to the adoption of Intelligent Transportation Systems (ITS) technologies. During this period, a number of critical factors came together including sufficient experience with the various ITS technologies; the development of backend data systems needed to house, integrate, and access the data; and the efforts of key personnel to “make the system work”. The majority of performance reports address various aspects of transit service at a given summary level for the complete system (e.g., all routes, all stops). This provided the agency with a snapshot of various states of the transit system at regular points in time. While this is important for archival purposes, the reports contain a large amount of useful information that is presently not being utilized by decision makers due to the sheer volume of information presented. Although the performance reports generated at TriMet have been successful in identifying scheduling and operational issues, a disjuncture exists with respect to the ability to convey important information to key decision makers including schedulers, service planners, and operations management personnel. This present study has two principal objectives: 1) to identify methods that serve to reduce the quantity and enhance the quality of the performance monitoring information and 2) to develop effective visualization techniques for presenting important findings to decision makers.

2. Background

2.1 Transit Performance Measurement

Performance measurement figures prominently in the ability of a transit agency to measure and monitor progress towards meeting specific objectives outlined in the strategic plan. Performance measurement is also used to determine how well an agency is adhering to it's service standards. Transit performance measures are highly flexible in that they can encompass multiple aspects of transit service that are of interest to both agencies as well as passengers. The performance measures of interest to transit agencies typically describe various aspects of service related to cost efficiency, cost effectiveness, and service effectiveness (Fielding, 1987) whereas customer-oriented measures tend to address issues related to transit availability, comfort and convenience, and safety and security (Kittleson & Associates et al., 2003). While performance measurement is particularly useful for identifying areas where operational problems exist such as the flagging over and unproductive routes or identifying routes operating at or below capacity, it is not end in itself. Fielding (1987) argues that the impetus for improving transit performance rests with managers who must ultimately decide whether to take corrective action, typically on a case-by-case basis, which also highlights the fact that performance measurement can be used to evaluate the success of various management interventions.

2.2 Transit Data Systems

While there has been a considerable amount of work undertaken in the areas of transit GIS and, more generally, visualization in transportation, specific research related to the visualization of transit data within the context of performance monitoring has generally been lacking. A notable exception is recent work by Peng et al. (2006) which looked at uses of AVL, APC, and GIS technologies in the area of transit performance measurement. The study by Peng et al. (2006) included a transit industry survey which found that while the overwhelming majority of transit agencies felt that AVL and APC data were useful for, or held promise for, transit performance measurement, most agencies did not actually monitor performance with data collected from these technologies. Furthermore, the industry survey found that only about 43% of the transit agencies used GIS for the analysis or reporting of transit performance data.

In discussing AVL and APC data applications, Furth et al. (2003) stated that the visualization of bus transit performance information was ”presently underexploited.” This may be partially due to the fact the data systems needed to support such activities have not sufficiently evolved at most agencies that collect ITS data (Furth, 2000). Efforts to make use if ITS data have often been hampered by problems with data collection, post processing, and integration with backend systems (Hu et al., 2002; Gordon & Shaver, 2004) as well as budget limitations, inadequate training of personnel, and lack of industry guidance (Peng et al., 2006). Problems also exist with respect to the ability to integrate ITS data with spatial data housed inside a GIS. These problems largely stem from incompatible file formats, issues surrounding the use of proprietary software, and difficulties associated with maintaining accurate spatial layers in a rapidly changing environment (Sutton, 2004). This is likely to change as agencies continue to migrate towards more general purpose relational database management systems, GIS software, and standard data models.

The use of GIS technology in transit agencies is widespread and the number of applications is quite formidable. In a 2003 industry survey, over three-quarters of the responding agencies indicated that they used GIS (Sutton, 2004). Several studies shed light on myriad of uses of GIS within transit agencies and the reader is directed to these publications for more detail (GIS/Trans, Ltd. 2001; Sutton, 2004; FTA, 2005). Regarding the transit GIS literature, approximately 25% of the publications to date can be classified as falling under the headings of either operations or management, with the majority of transit industry publications related to service planning (Sutton, 2004). The majority of studies that use GIS technology to integrate, analyze, and display AVL and APC data can generally be characterized as "one-off projects", with examples of GIS being used to support of longer term business practices generally lacking.

The use of GIS at transit organizations is rapidly evolving, yet becoming more stratified over time. According to Sutton (2004), there are three general levels of GIS integration with an agency including: 1) use in support of specific *project* tasks, 2) use as a *departmental* resource in support of an agency's business practices such as planning, scheduling, and real-time bus operations, and 3) use as an *enterprise* system where GIS is incorporated into an agency's information technology infrastructure (Sutton, 2004). Much of the impetus behind the transition of GIS away from the desktop to becoming more fully integrated within an organization can be attributed to synergistic effects resulting from the confluence of ITS, GIS, and information technologies and a desire by management to more fully leverage ITS data to support business decision making.

GIS figures prominently in transit data visualization because it is a powerful platform for integrating data from disparate sources and because maps help facilitate cognitive understanding of spatial patterns, relationships, and trends. This is largely accomplished through use of feature symbology, the classification of attribute values, raster-based imagery, and surface visualization. Much of what has been described thus far falls within the domain of GIS for Transportation (GIS-T)—an emerging field focused on the development and use of an “enhanced” GIS for transportation research, planning, and management (Thill, 2000; Miller & Shaw, 2001). Efforts to effectively store, manage, and manipulate transportation data contained in a GIS are greatly facilitated through use of well designed data models, which relate to the conceptual organization of transportation features and attributes in a database, and data warehousing, which can effectively link multiple backend data systems, thus providing ready access to data for analytical purposes.

2.3 Transit Data Visualization

New analysis tools are needed to assist with the detection and quantification of transit performance problems. Langendorf (2001) argues that the ability to understand complex phenomena often requires investigation from multiple viewpoints using a variety of data sources and that visualization can serve to enhance communication among the participants in the problem solving process. Data visualization can also be used for exploratory analysis, pattern identification, and the development of hypotheses (Miller & Shaw, 2001). Oftentimes, a distinction is often made between “visual thinking”, which is exploratory in nature and helps with preliminary investigation of problems, and “visual communication”, which is concerned with explanation and presentation of findings (DiBiase et al., 1992). Advanced transit performance monitoring applications can readily embrace both concepts.

A paucity of studies exist related to visualization of transit performance data over time. Of the studies that do exist, the majority are based on aggregate data such as that collected annually for National Transit Database reporting (Florida Department of Transportation, 2004; Polzin & Page, 2003; U.S. Department of Transportation, 2002). Information graphics in the form of charts are typically used to convey information about a single attribute measured at regular time intervals. While highly aggregate performance measures are important from a managerial perspective, they tend to mask a substantial amount of the variability occurring at more disaggregate levels such as routes, blocks, trips, stops, time periods, days, or even operators. Efforts to increase system-level performance rest squarely on the ability to identify the causes of unreliable service at sub-system levels so that targeted interventions can take place.

Most transit GIS applications focus on a particular aspect of transit service occurring within geographic space at a single point in time. Temporal GIS is characterized by Burrough (1986) as a “set of tools for collecting, storing, retrieving at will, transforming, and displaying spatially and temporally referenced data from the real world for a particular set of purposes” (as cited in Stead, 1998, p. 214). Zhao & Shen (1997) argue that a temporal GIS can be used to increase the range of transit potential applications, thus aiding knowledge discovery.

The temporal nature of transit service is shown in Figure 1. Individual stops (S) are sequentially ordered in space along the Y-axis while consecutive runs (R) are represented on the X-axis. Two different time snapshots are shown along the Z-axis (Time 1 and Time 2). The data structure is highly flexible since stops can be aggregated to time points or routes; runs can be aggregated to time periods (e.g., peak, midday, etc.); and time can be aggregated over weekdays, months, bookings, etc.

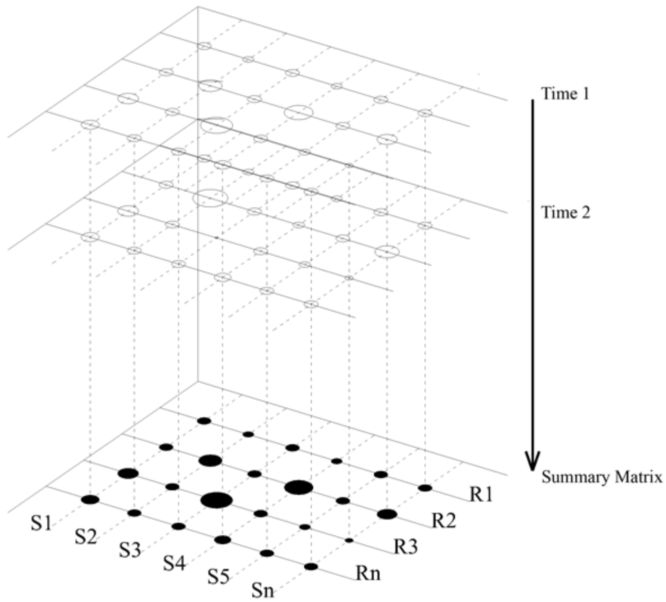
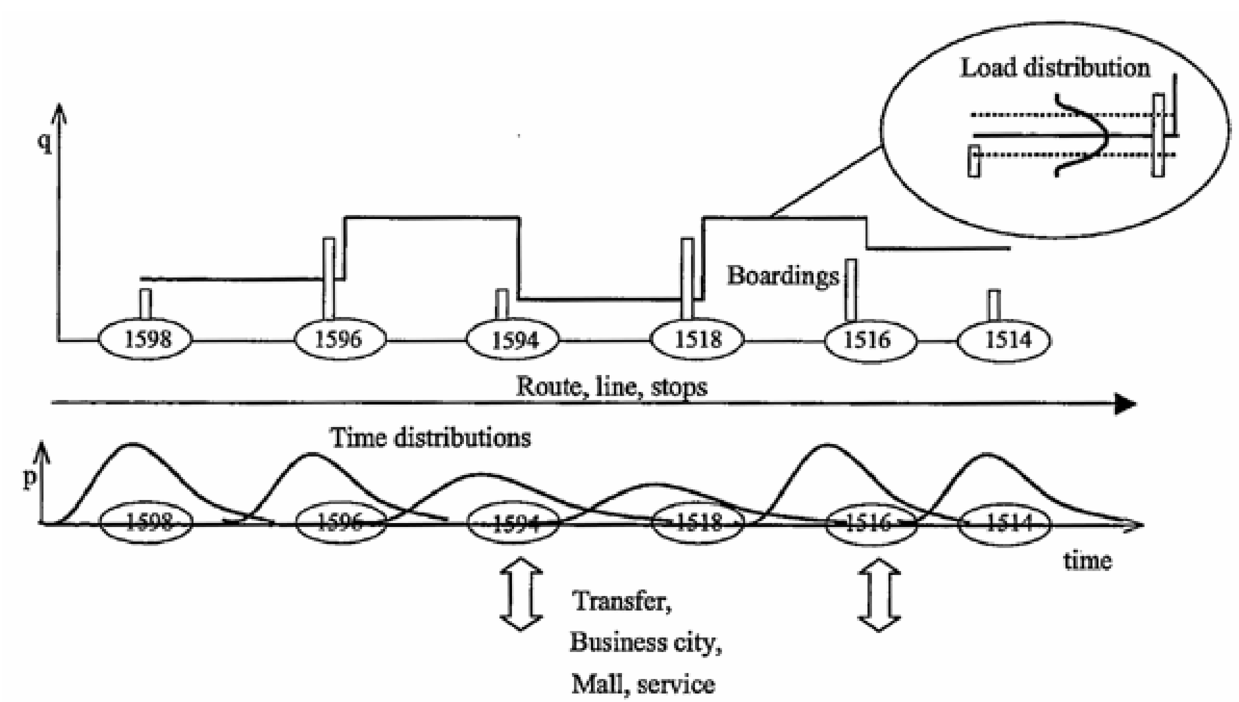


Figure 1: Transit Service in the Temporal Dimension

There are three general approaches to addressing time inside a GIS with respect to performance monitoring. The first concerns calculating the difference in the values of a performance metric associated with a particular geographic feature between any two points in time, then subsequently displaying the result on a map. An example would be calculating the net or percent change in excess passenger wait time at stops between quarterly bookings for a given route, direction, and time period. The second approach concerns estimating the means or variances of an attribute over multiple time intervals. This also produces a single estimate where the notion of time is incorporated into the actual measure itself. For example, one can calculate the amount of variability in passenger boardings at stops over four consecutive bookings in order to measure the consistency of stop-level demand. The third principal way to display information in the context of a temporal GIS is to ignore temporal computations altogether and simply display the time slices as a series of individual panels or in rapid succession in what amounts to a video animation. Both of these methods depict temporal change across geographic space. An example is provided in the work of Galindez and Mireles-Cordova (2001) who summarized passenger load ratios by census tracts in order to evaluate changes in passenger activity occurring over the morning peak time period. The results were presented a series of sequential images representing various states of the transit system in 20 minute time intervals.

Another important consideration with respect to transit data visualization concerns the ability to display multiple variables simultaneously. A report by Lehtonen at al. (2002) contains a highly detailed, abstract figure of a line profile (Figure 2). The authors incorporate multiple stop and



Source: Lehtonen at al. (2002)

Figure 2: Abstract Line Profile

distance-based performance measures in a single graphic image including average boardings per stop, average passenger load between stops, the load distribution between stops, scheduled departure time, and arrive time variability at stops. High demand locations and transfer stops are clearly labeled. The figure is notable in that it shows how numerous measures of central tendency and dispersion can be simultaneously presented in a manner that is comprehensive, yet simple to understand.

3. Problem Statement

Performance measurement is critical for the successful management of transit operations. Performance measurement not only helps an agency determine whether or not it is meeting its strategic objectives but can also be used to evaluate the success of various programs, plans, and projects. Performance measurement capabilities have greatly expanded in recent years largely because of advancements in information technologies and a desire to use the information generated from ITS technologies to identify and fix operational inefficiencies. While numerous data visualization examples can be found in the literature, the visualization techniques have not kept pace with performance reporting since most information is still presented in tabular format. It is also evident that there is a key role for GIS technology in transit data visualization and that the time element has not been fully exploited. Visualization techniques that make use of multiple variables are able to provide additional insight into the potential causes of transit service problems. The question arises as to how best to incorporate data visualization techniques into transit performance reporting in a manner that 1) highlights the most important information relevant to decision makers 2) using a variety of presentation formats, 3) is comprehensive, and 4) is largely automated.

4. Research Objective and Methodology

The present study utilizes TriMet as a case study. The aim of the research is to shed light on transit performance reporting practices at TriMet and to show how data visualization techniques can be used to enhance decision making capabilities within transit agencies. TriMet employs a variety of methods to call attention to critical operations and scheduling problems. In addition to regular, ongoing performance reporting, the agency has developed a number of custom software applications allowing for the query and display of transit performance information needed by operations managers for near term decision making. The study concludes with example data applications showing how transit performance information can be visualized using time-distance diagrams and GIS technology.

5. Findings

5.1 Transit Performance Reporting at TriMet

TriMet undertakes transit performance measurement at regular reporting intervals. An overview of the majority of the "static" performance reports produced by TriMet relating to fixed-route bus service is presented in Table 1. The summary level of the information contained in each report varies according to the target audience. For example, schedulers require information about the characteristics of service reliability at time points, passenger activity over time points, and passenger loads at maximum load points whereas service planners require information about route level productivity and passenger demand at stops. In most cases, TriMet generates separate performance reports for each day type consisting of weekday, Saturday, and Sunday service. The majority of the performance reports are generated on a semiannual basis, with the main exception being the route performance reports which are undertaken quarterly.

Table 1: TriMet Performance Reports for Fixed Route Bus Service

Performance Report	*Summary Level*	*Day Type*	*Reporting Freq.*
Route Performance			
Route Ridership (1)	Rte	All	Quarterly
Peak Period Ridership	Rte-Dir-Peak Period	All	Quarterly
Time of Day Route Performance (2)	Rte-Dir-Time of Day	All	Quarterly
Service Delivery (3)	Rte	All	Quarterly
Time of Day Performance	Rte-Dir-Time of Day	All	Quarterly
Time of Day Ridership (4)	Rte-Dir-Time of Day	All	Quarterly
Trip Level Performance	Rte-Dir-Trip	All	Quarterly
Service Standards			
Hourly Capacity (5)	Rte-Dir-Trips/Hour	All	Biannual
Trip Level Hourly Capacity (6)	Rte-Dir-Trip	All	Biannual
Hourly Excess Capacity (5)	Rte-Dir-Trips/Hour	All	Biannual
Trip Level Hourly Excess Capacity (6)	Rte-Dir-Trip	All	Biannual
Deadhead Trips with Excess Capacity (7)	Rte-Dir-Block	Weekday	Biannual
Less Productive Tripper (8)	Block-Piece	Weekday	Biannual
Route Level Ridership			
Route Level Ridership (9)	Route	All	Quarterly
Route Level Ridership	Route	All	Annually
Weekly Route Level Ridership (10)	Route	Weekly	Annually
Route Level Ridership (*)	Route	Weekday	Annually
Route Level Ridership & Veh Hours (*)	Route	Weekday	Annually
Passenger Censuses			
Time Point Segment Ridership	Rte-Dir-TP Segment	All	Biannual
Time Point Segment Ridership	Rte-Time of Day-TP Segment	All	Biannual
Route & Stop Level Passenger Census	Rte-Dir-Stop	All	Biannual
Stop Level Passenger Census	Stop	All	Biannual
Stops All (*)	Stop	All	Biannual
Cordon Counts			
All Day Cordon Counts	Rte-Dir-Block @ Max Load Point	All	Biannual
AM Cordon Counts	Rte-Dir-Block @ Max Load Point	All	Biannual
PM Cordon Counts	Rte-Dir-Block @ Max Load Point	All	Biannual
All Day History (*)	Rte-Dir @ Max Load Point	All	Biannual
AM Peak History (*)	Rte-Dir @ Max Load Point	All	Biannual
PM Peak History (*)	Rte-Dir @ Max Load Point	All	Biannual

(1) Report provides comparison to previous year's values, same quarter- boarding rides, rides per vehicle hours, net difference in boarding rides, percent change in rides per vehicle hour
(2) Multiple reports generated- sorted by percent late, excess wait, and headway adherence
(3) Report provides comparison to previous year's values, same quarter- on time percent
(4) Multiple reports generated- sorted by rides per revenue hour, maximum load
(5) Individual report sorted by load to achievable capacity ratio > 80%
(6) Individual report sorted by load to achievable capacity ratio < 50%
(7) Individual report sorted by maximum load factor < 50%
(8) Individual report sorted by boardings per platform hour < 20%
(9) Report provides comparison to previous year's values - boarding rides, rides per vehicle hours, net difference in boarding rides, percent change in rides per vehicle hour
(10) Multiple reports generated- sorted by total ridership, rides per revenue hour, rides per vehicle hour
(*) Denotes that report provides summaries over time at level of reporting frequency

Performance reports denoted with an asterisk (*) highlight examples where certain measures are tracked over multiple time periods. For example, one of the route level ridership reports tracks total weekday boardings by year. Footnotes 1, 3, and 9 indicate the reports that provide a basis for comparison to values from the previous year. Other techniques for calling attention to operational problems include sorting the reports by different performance measures (Footnotes 2, 4, 10) and by limiting the number of cases that to those that exceed predetermined threshold values (Footnotes 5-8).

The examples presented in Table 1 highlight several important features related to “standalone” performance reports. The first concerns the fact that much of the information contained in the static reports is either redundant or simply not relevant. Redundancy is particularly evident in the static reports that differ only in the particular variable used as the basis for sorting. Irrelevancy relates to the fact that the majority of the information is simply not important from a management perspective since it represents service performing within acceptable bounds. It is also evident that the ability to monitor longer term trends is presently not being exploited to its fullest potential. For example, knowing whether the number of lift operations occurring in a time point segment is trending upwards or downwards would be an important piece of information for schedulers. The use of information graphics such as charts is also lacking which is surprising given their ability to further summarize tabular data and call attention to important relationships.

5.2 Reporting Enhancements

Compared to static performance reports, a far more flexible and efficient method for presenting transit performance information is through a custom query interface connected to a backend database. Rather that determining a priori how best to structure each performance report, reporting systems can be developed with built in tools allowing users to interactively filter and sort information to provide access to highly specific information more quickly. Another technique that can be used to enhance tabular output is to highlight values that exceed certain thresholds by varying text colors and/or cell background colors—a technique referred to as traffic lighting. Figure 3 is a case in point where a different text color has been applied to extreme values in a standard performance report. By using such a technique, one can readily determine that because Trains (Blocks) 7240 and 7242 are running hot, that patrons on subsequent vehicles are experiencing poor quality service in the form of overloaded buses and longer wait times.

Peak Hour Service Standards Report | *Weekdays* | *Spring 2004 Quarter*

Hourly Capacity Report: Based on Achievable Capacity

72 -Killingsworth-82nd Ave - Inbound 11:15 AM - 12:14 PM @ 82nd & MAX Overpass

Hourly Load	Seat Capacity	Achievable Capacity	Load to Seat Ratio	Load to Achievable Capacity
273	234	307	117%	89%

Start Time	TP Time	Train	Start Location	Avg. Boarding Rides	Avg. Max Load	Max Load Factor	Percent Over Capacit	# of Pass Ups	APC Obs.	Headway Adher-ence	On Time	Early	Late
10:39 AM	11:15 AM	7244	Anchor & Channel	84	35	91%	3%	1	38	98%	96%	1%	4%
10:50 AM	11:27 AM	7240	Anchor & Channel	109	45	117%	9%	5	34	88%	76%	11%	13%
11:02 AM	11:39 AM	7235	Anchor & Channel	115	53	136%	43%	1	42	76%	68%	2%	30%
11:15 AM	11:51 AM	7237	Anchor & Channel	104	48	124%	28%		43	80%	85%	0%	15%
11:25 AM	12:02 PM	7242	Anchor & Channel	94	42	107%	14%		44	81%	76%	10%	14%
11:37 AM	12:14 PM	7241	Anchor & Channel	126	49	125%	29%	11	42	70%	53%	0%	47%

Figure 3: Traffic Lighting Example

An additional technique that can be used to aid comprehension is hyperlinking which is an efficient method for gaining access to supplementary information. Since most enterprise level database and GIS systems are web-enabled, hyperlinking can be effectively used to gain access to ancillary information in the form of tables, charts, and maps.

The reports that have been discussed up to this point by no means represent the totality of performance monitoring capabilities at TriMet. A number of performance monitoring applications have been developed that use an MS Access front end to retrieve data housed in an Oracle database. These applications provide schedulers and garage managers with access to information on bus operations and operator performance on a next day basis. Data can be retrieved for any given day, the current booking, or previous bookings. Efforts are currently underway at TriMet to elevate certain performance monitoring functions to the enterprise level, thus making the information available to a wider array of business units. Two notable examples include a system for transit operator management aimed at improving service quality and service productivity and an application called the Bus Dispatch System Data Displayer (BUDS) which provides a mechanism for querying and displaying archived AVL and APC data. BUDS allows users to query any block over a several month period and plot the vehicle's GPS points on a map while also presenting output in the form of an MS Excel table.

5.3. Example Applications

Several transit data visualization examples are presented in the following section. The primary areas that are explored include: 1) the general mapping of information representing quantities, 2) linear referencing, 3) time-distance diagrams, and 4) 3-D visualization. In many of the applications, a limited set of data was employed since the main purpose is to present ideas and facilitate discussion.

5.3.1 Mapping of Quantities

By far the simplest method for visualizing performance data using a GIS is to render quantities of an attribute by varying it's symbology either by graduated color, by graduated symbols, by proportional symbols, or by dot density. An example of rendering quantities using proportional symbols is presented in Figure 4. Event data related to unscheduled stops with dwell times greater than 30 seconds on Route 14 is presented. The data indicate that excessive dwells associated with unscheduled stops in the outbound direction tend to occur downtown on the

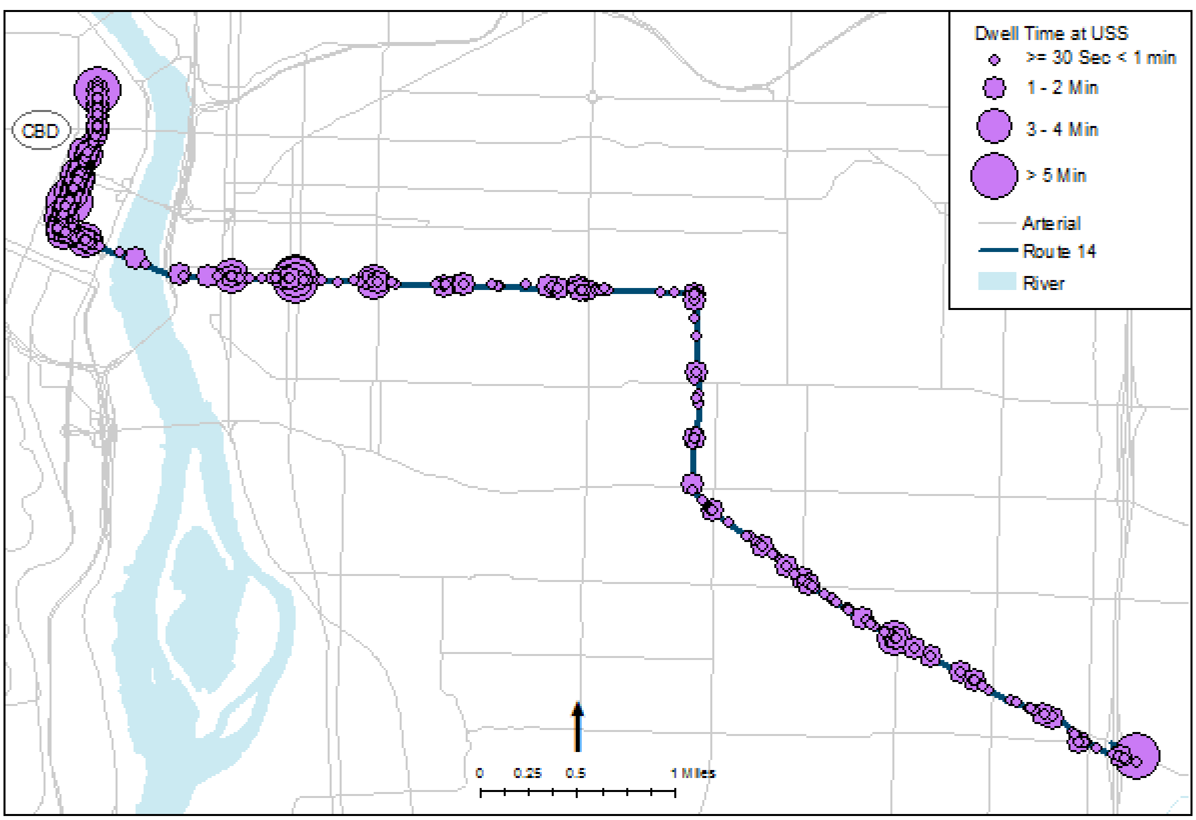


Figure 4: Dwell Time > 30 Seconds at Unscheduled Stops, Route 14 Outbound, 5 weekdays.

transit mall (where the majority of boardings occur) and at locations where the route intersects major arterials (where congestion, signalization delays, and transfer activity occurs). Since the spatial pattern of dwell time delay could also be explained by other confounding factors including vehicle holding actions to maintain schedule adherence and facilitate transfers; problems traversing signalized intersections; and bus crowding on the transit mall, additional contextual information is clearly needed. Another method for displaying quantities is through use of chart maps. The example provided in Figure 5 shows weekday on-time performance at time points for Route 14 displayed as a series of pie charts. The information presented shows the classic pattern of delay setting in as distance along the route increases. Interestingly, a large percentage of buses that were on-time at the second to last time point are arriving at the terminal location early. Similar techniques to the ones just mentioned can also be used to display event data which are not tied to specific stop locations. Examples include fare evasions, passups, and safety and security incidents.

5.3.2 Linear Referencing

Although linear referencing is commonly used in the transit field in the area of asset management and to georeference transit features to street centerlines, there is little evidence of its use for performance monitoring purposes. Given that dynamic segmentation provides an efficient way to relate point and line events contained in tables to distance along routes, this is somewhat surprising. This may be partially due to the fact that modern AVL systems measure the movement of vehicles, passengers, operators, and events at precise XY locations, largely obviating the need to display attributes according to distance along linear features. For example,

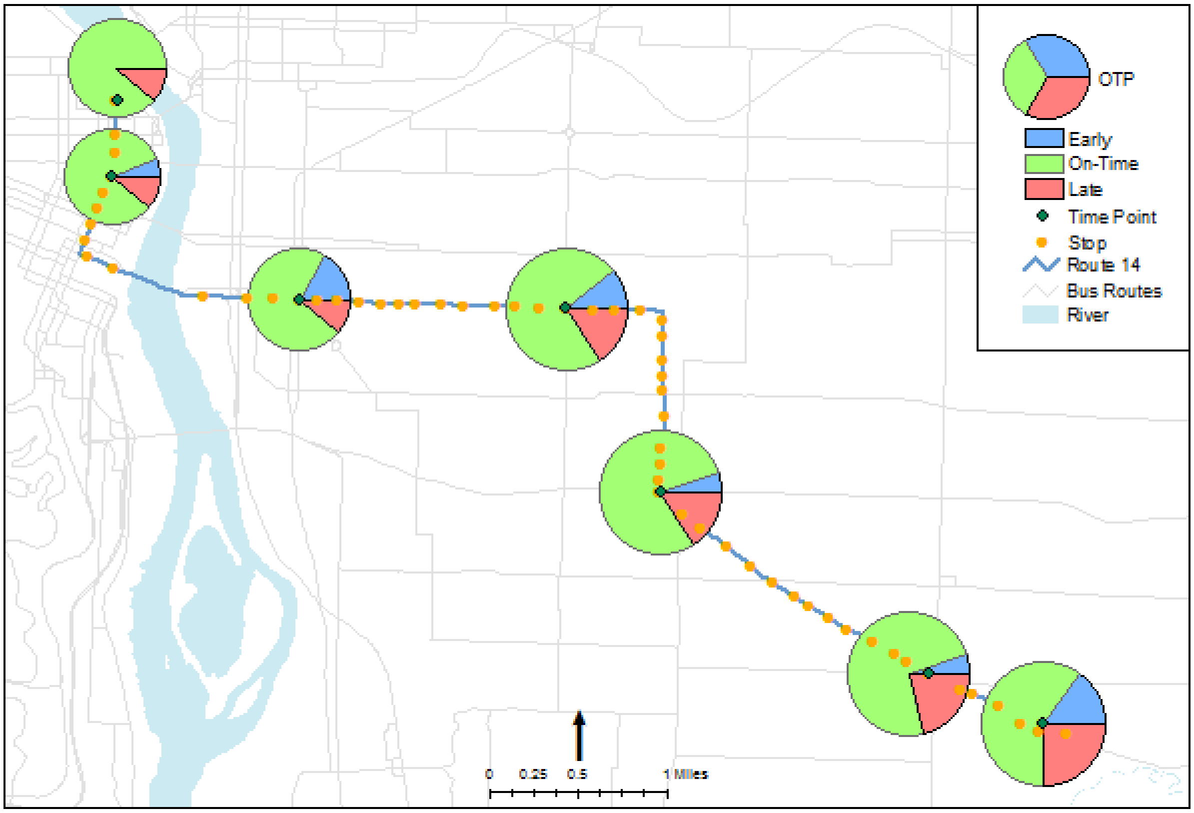


Figure 5: On-Time Performance, Route 14 Outbound, Weekdays in June

there is no real benefit to displaying dwell time or passenger demand at stops using a linear referencing system compared to using actual XY location. However, there are several instances where a linear measurement system would be useful including cases where the value of an attribute changes in relation to distance such as the display of passenger load flow information (Figure 6) and cases where there is a need to display multiple attributes simultaneously (Figure 7).

Load flows based on total daily passenger loads are presented in Figure 6 for Route 20 in the inbound direction. The information shows that passenger loads are heaviest just prior to the Gateway Transit Center and immediately adjacent to the downtown area. Another performance measure that could be presented in a similar manner is cumulative running time delay. The graphic image presented in Figure 6 could also have been generated without the use of a linear referencing system by segmenting the bus route at each stop location, assigning passenger loads to the individual segments, and then varying the line widths according to the load value. That said, it is much simpler to generate an event table using a relational database than to use geoprocessing techniques to snap bus stops to routes and then split routes into multiple segments.

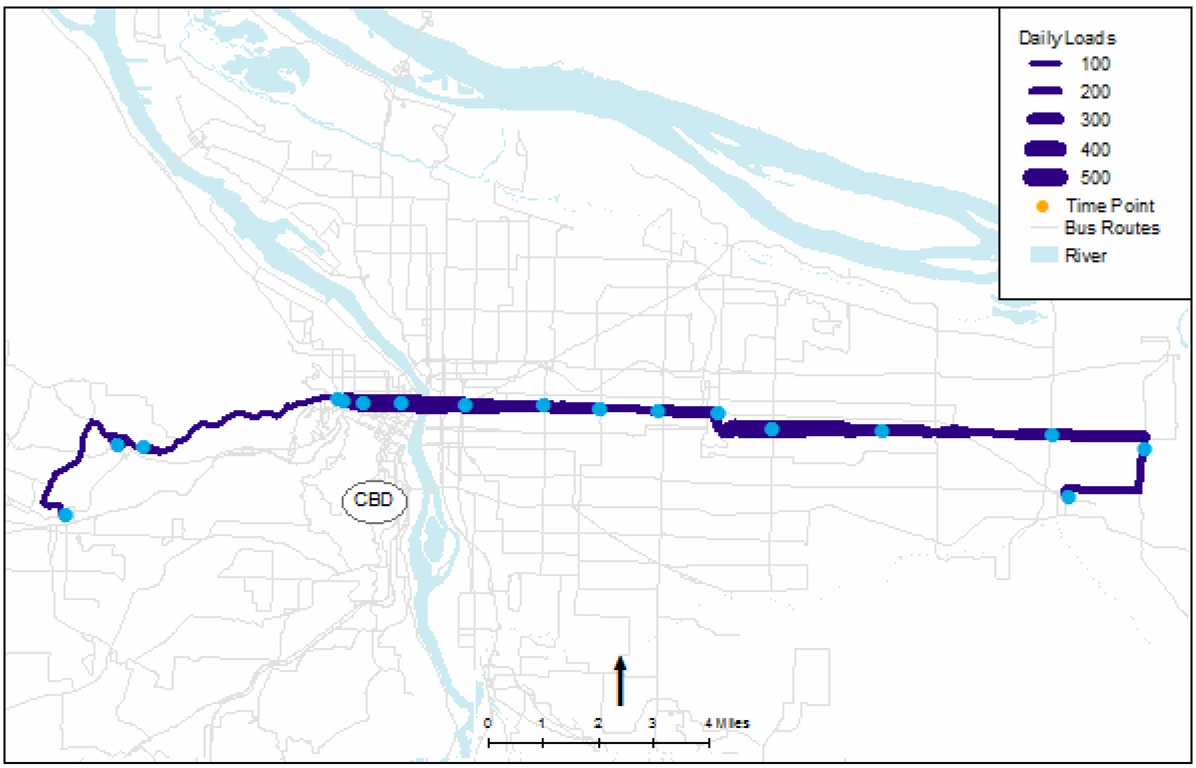


Figure 6: Total Daily Passenger Loads, Route 20 Inbound (East-West), One Day, All Trips

Figure 7 displays passenger load variation in relation to running time delay variation. The figure is also based on a linear referencing system except the route has been broken into time point segments where each segment is proportionally true to distance, yet the linear features have been

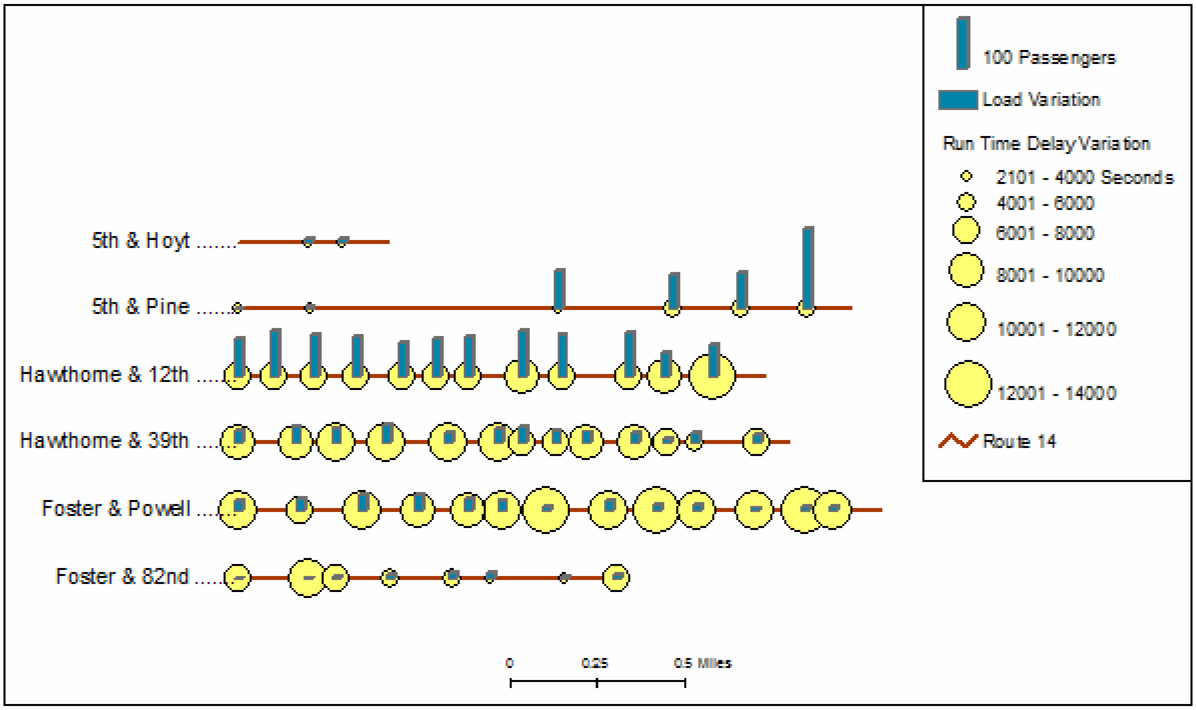


Figure 7: Load and Run Time Delay Variation, Route 14 Outbound, Trip 1575, 5 Weekdays

straightened in order to simplify the presentation of information. Figure 7 provides for accurate spatial representation with respect to distance, yet is much more flexible with regards to the display of performance information since each route in the system (which vary considerably with respect to distance) can be broken into time point segments and displayed in a consistent manner. Longer routes with more time points would simply have more segments displayed. This is in contrast to the use of maps, where variable route lengths would require that the information be displayed at different spatial scales.

5.3.3 Time-Distance Diagrams

Bruun, Vuchic, and Shin (1999) argue that time-distance diagrams are grossly underutilized at North American transit agencies. This is somewhat surprising given their overall usefulness for identifying bus operations and scheduling problems and evaluating the effectiveness of management interventions. Time-distance trajectories for four PM peak period outbound trips on Route 14 are displayed in Figure 8. This one simple diagram provides insight into the relationship between actual and scheduled service on a per trip basis as well as the spacing of vehicles between successive trips—at any point in time and space (e.g., at each time point) as well as over time and space (e.g., between time points). These relationships would be difficult to identify if the data were presented in tabular format. For example, 244 data points were required to generate Figure 8—four variables consisting of trip ID, schedule time, arrive time, and cumulative distance from the route origin * 61 stops.

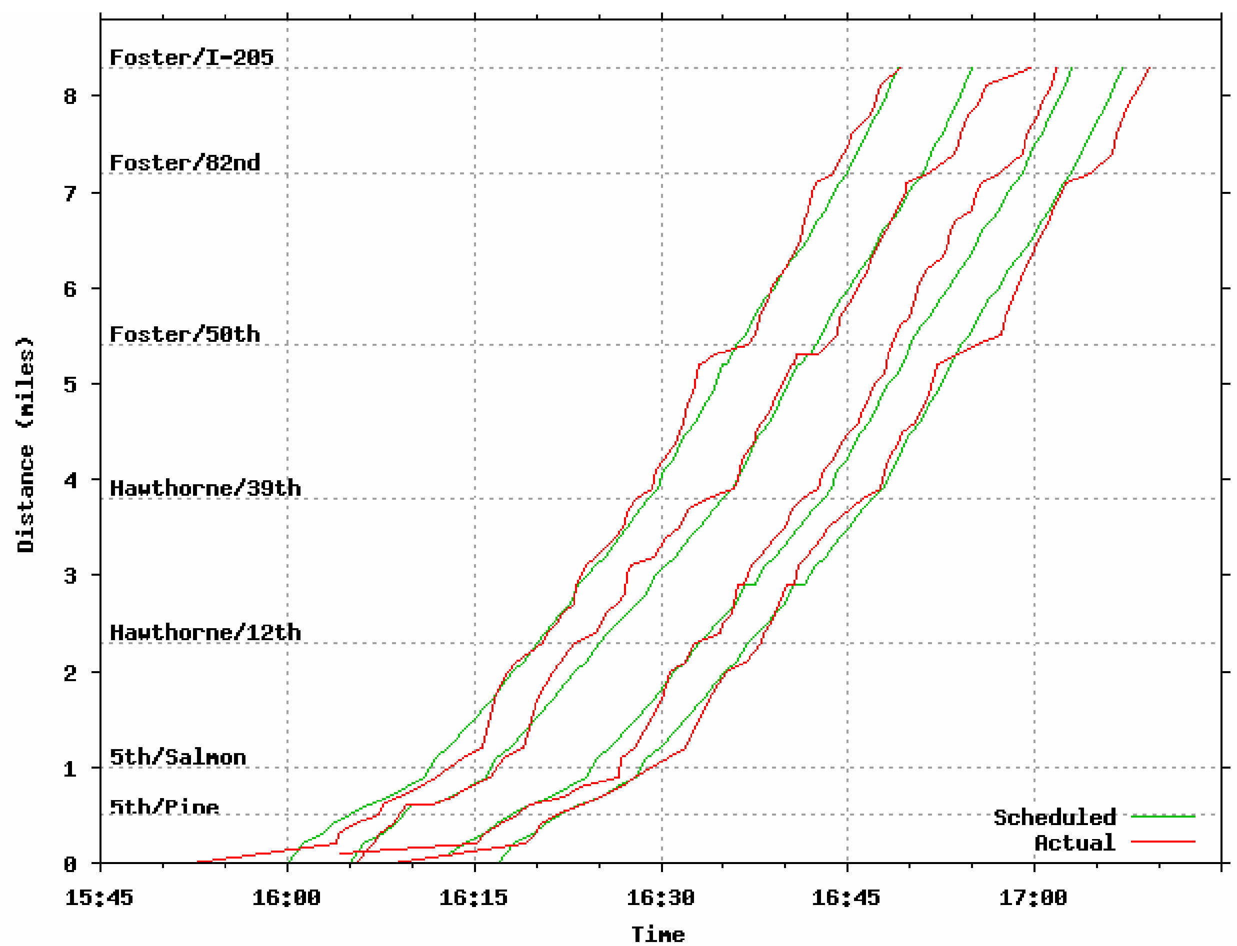


Figure 8: Time-Distance Diagram, Route 14 Outbound, 4 trips

TriMet schedulers make regular use of the BDS Graph component of a legacy scheduling application named the Interactive Schedule Mapper which is used to visually display AVL and APC data (Figure 9). The left-side panel in the figure represents the “early-late” window and shows the amount of deviation from schedule, run time deviation, idle time, and lift operation time. The solid white vertical line represents on-time. Points the right of the vertical line are early whereas points to the left are late. The colored lines represent day of week. Schedule time at time points in minutes post the hour are shown in the time scale window (the narrow center column). The right-side panel can display either passengers or stopping activity for a single trip or multiple trips. Passenger activity information includes the start and end loads at each time point, the maximum load, and the number of boarding and alighting passengers.

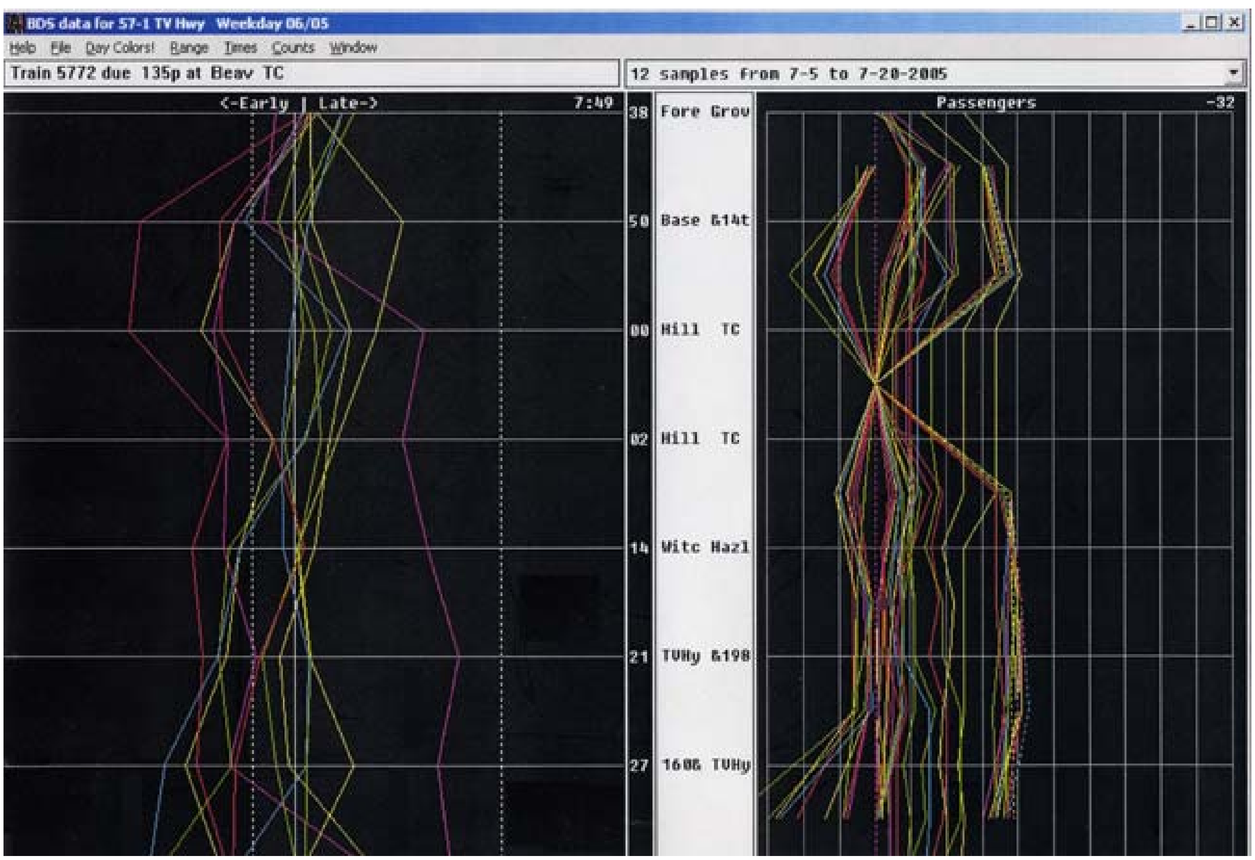


Figure 9: APC Graph Example, Route 57 Inbound

Stopping activity information includes the actual number of passenger stops, idle stops, and lift operations between time points. The application is highly flexible in that the analyst can set various parameters such as the number of sampled trips, booking, route, direction, trip, day type. The analyst can interactively expand or compress the time scale, scroll the trips horizontally, and also chose between displaying the performance measures as counts, averages, or variances. Operator ID can also be displayed. While not a "true" time-distance application since time points are spaced evenly without regards to distance and time in the horizontal scale is relative to on-time, the application is more than adequate for scheduling purposes. BDS Graph is powerful data visualization tool because of its interactive nature and because of the large amount of related information can be displayed simultaneously.

Time-distance graphs can and should be used more widely as a data visualization tool in transit performance monitoring since they can effectively summarize vast quantities of information in a manner that sufficiently captures the dynamic nature of transit service. For example, time-distance diagrams can provide insight into the interrelationship between service delays and variations in passenger activity. The diagrams can be used to identify how delays at trip origins can impact downstream performance and passenger loads as well as provide insight into the amount of recovery time needed at route termini.

5.3.4 3-D Visualization

Certain types of transit performance information can be analyzed and displayed in the third dimension, thereby providing additional insight into spatial patterns that cannot be realized in two dimensions alone. Figure 10 is an example of a two dimensional image showing average weekday boardings at bus stops associated with TriMet fixed route service. Figures 11 and 12 show the same information in three dimensions, the first by extrapolating average daily boardings at bus stops to the Z dimension and the second by using a raster-based 3-D surface analysis technique. In comparing Figures 11 and 12 to Figure 10, one can more readily identify high demand locations within a regional context as well as identify locations were transit is underutilized (or where areas are underserved). 3-D visualization is an appropriate technique for displaying transit performance information measured at point locations such as stops, time points, maximum load points, and event locations. The Z- dimension can be modeled as counts, net differences, averages, deviations from schedule, and variances.

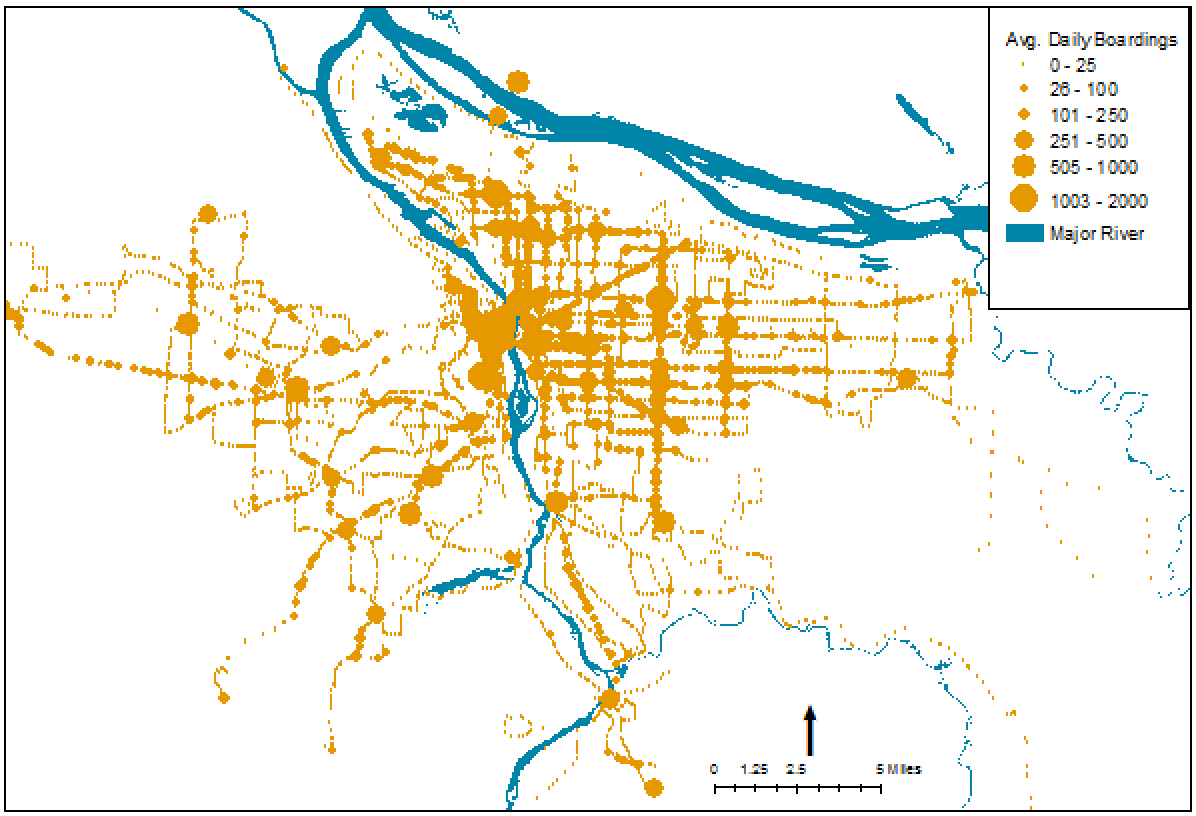


Figure 10: Average Weekday Boardings at Stops, Fall 2005, 2-D Representation

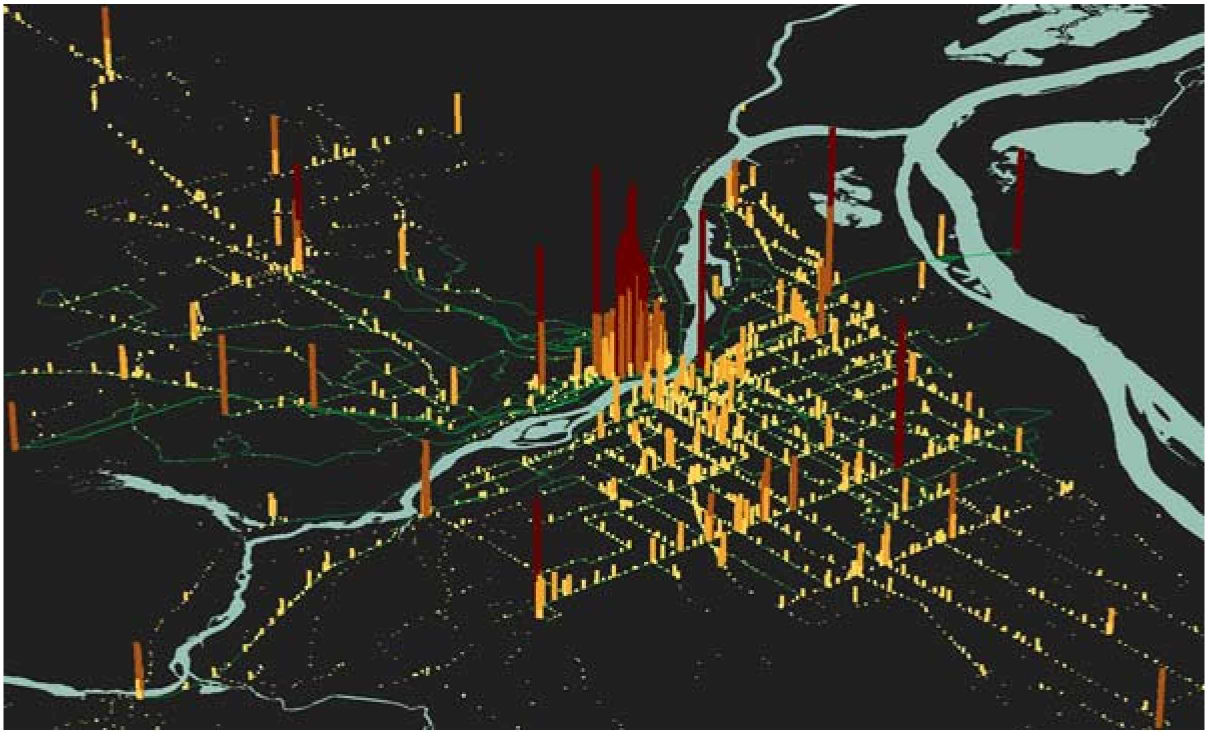


Figure 11: Average Weekday Boardings at Stops, Fall 2005, 3-D Representation

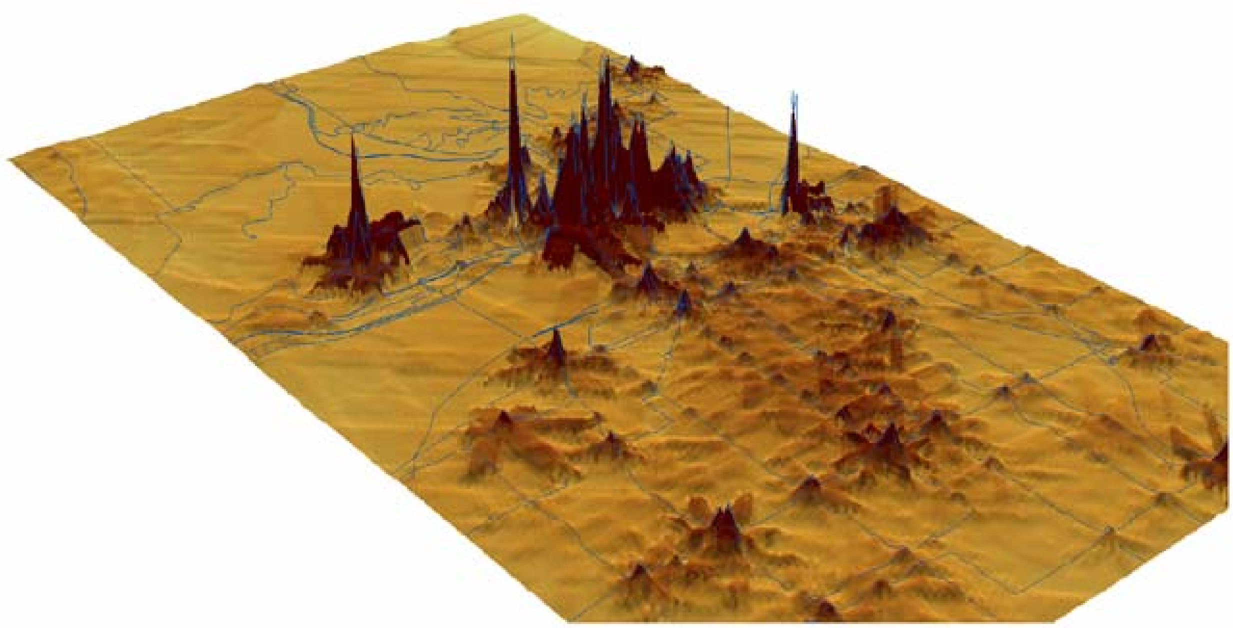


Figure 12: Average Weekday Boardings at Stops, Fall 2005, 3-D Surface Representation

6. Conclusions and Recommendations

The convergence of ITS, information technology, and advances in GIS present a unique opportunity to take performance reporting to the next level through continued development of user friendly data query and display interfaces and by extending current data visualization techniques. In surveying the literature, is apparent that a most of the data visualization examples to date are related to specific, one-off projects and are not part of longer-term performance monitoring and evaluation programs. Techniques for creating information graphics on-the-fly or as batch processes which can automatically generate graphic output for the complete system can readily be developed using modern database, GIS, and statistical analysis software.

Much can be done to improve the readability of tabular output including the use of traffic lighting which can help call attention to operational problems; the use of hyperlinking to provide immediate access supplemental information in the form of tables, charts, and maps; and the development of interactive software applications for data query and display purposes. Such applications can target specific business needs related to the day-to-day management of transit operations and can also be used as part of longer term performance monitoring and evaluation programs. Information graphics in the form of charts, maps, and abstract diagrams can and should be more fully leveraged because of their ability to further summarize what would normally be tabular data, greatly aiding the understanding of complex phenomena. While maps can be used to present spatial information with a high degree of accuracy, it is apparent that space and time can be abstracted with little loss of information. It is also evident that transit data visualization techniques capable of displaying multiple transit performance measures at one time can do much in the way of helping to explain important relationships. Specific data visualization techniques worthy of additional exploration include those making use of temporal GIS, time distance diagrams, and linear referencing.

It can be argued that transit data performance monitoring and transit data visualization are still in their infancy since few transit properties have mature enough data systems and sufficient experience using ITS data for performance monitoring purposes. This should gradually change over time as agencies learn how to more fully leverage transit service performance data to improve service efficiency and service quality.

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