Arriving Next on Track 1: An Online Geospatial Transit Performance Data Archive

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Abstract. This paper describes a successful initiative in Portland, Oregon to develop a web-based, geospatial transit performance data archive. The transit industry collects vast quantities of performance data. In addition, archived data user services have evolved to a high level in the highway arena; however, there is a conspicuous absence of comparable (online, public, interactive) data archives for transit. In response to a request from TriMet, which sought help with spatial visualization of its performance data, a team at Portland State University used a combination of open- and closed-source software to create a network layer on which stop- and segment-based performance measures could be displayed. The team then created a web-based application that provides individual users the ability to run custom queries as well as other functions. The primary outcome is increased understanding of transit operations and an enhanced ability to inform high-level decision making. The secondary outcome is the benefit to the research community of a data archive that is now genuinely multimodal. Future work will focus on upgrading the flow of data from quarterly to real-time, which requires considerable work in the management of data quality. The methods by which the team visualized agency performance data and provided web-based access are replicable by other transit properties, particularly those with General Transit Feed Specification (GTFS) data.

INTRODUCTION

This paper describes an effort undertaken by researchers at Portland State University (PSU) to develop a web-based, geospatial transit performance data archive. Using quarterly batches of quality-controlled ridership data from the Tri-County Metropolitan Transit District of Oregon (TriMet), the PSU team first developed a protocol for mapping transit ridership and service metrics in an offline geographic information systems (GIS) environment. The team subsequently developed an online, interactive application that allows a user to query and map those data.

In a 2006 TCRP report, Furth et al. described the transit industry as being "in the midst of a revolution from being data poor to data rich" and noting that this revolution would "open the door for new analysis methods that can be used to improve monitoring, planning, performance, and management." (*1*) That TCRP report focused on a number of analyses that could be enabled by the data from Automatic Vehicle Location (AVL) and Automated Passenger Counter (APC) technologies: targeted investigations; running time analysis; schedule adherence, headway regularity and passenger waiting time; demand analysis; mapping; miscellaneous operations analysis; and, higher level analysis.

TriMet is widely noted as an early adopter of intelligent transportation systems (ITS), including AVL and APC. In a TCRP case study on TriMet's use of ITS data for market research, Strathman et al. cite TriMet's initial adoption of APC technology in the early 1980's and AVL starting in 1998 (*2*). TriMet has made extensive use of the data from these systems, conducting each of the analyses described by Furth et al. to varying degrees.

However, despite its status as an industry leader in the use of ITS data, TriMet has encountered two common shortcomings. First, it has found only limited ways to visualize its data and this has limited the benefit that TriMet's data "richness" can offer to its management-level decision-making. Second, in comparison to highway operations, sustained streams of TriMet's data have not made it into accessible online archives that provide the basis for innovative research.

BACKGROUND

Data collection is ubiquitous in transportation. The Highway Performance Monitoring System (HPMS) has been in place since 1978 to inventory highway infrastructure and how it is used. The National Transit Database is almost as old, collecting information from transit properties about service provided and consumed.

The advent of intelligent transportation systems revolutionized the landscape by adding the prospect of continuous and sometimes even real-time collection of data with greater coverage. In most cases, data collection technology has been deployed in support of an operational strategy: detecting incidents on freeways, controlling traffic signals on arterials, and enhancing dispatch of transit buses. As a rule, the applications consumed data but did not warehouse or archive it.

The first wave of interest in archived data reflected the appetite of planners to inform and calibrate their analyses with the newly enlarged pool of information. A subsequent (and much more recent) wave of interest has come from the community of developers of mobile applications.

The following subsections describe the evolution of transportation data archives in general and transit data archives specifically.

Archived Data User Services

In September 1998, the United States Department of Transportation adopted an addendum to the *ITS Program Plan* to address Archived Data User Service (ADUS). The stated goal is "the unambiguous interchange and reuse of data and information."(*3*)

Since 1998, several transportation data archives have emerged. For example, FHWA's Office of Highway Policy Information website provides links to eight online archives: California, Maryland, Minnesota, Texas, Oregon, Virginia (two), and Washington.

Almost exclusively, these data archives rely on detection hardware installed in the highway right of way, although alternative sources including cell phone probes, are growing rapidly. Although the technology varies, the data generated generally include speed, volume and (lane) occupancy. Some systems are capable of classifying vehicle type. Most data archives also receive complementary sources, such as weather, incidents and special events.

Over the years, the industry has witnessed advances not only in the production and collection of data but also the distribution and accessibility of data. Some of the online data archives offer sophisticated visualization tools. The ability to view traffic data spatially and to observe trends over time represents a significant advance in transportation management.

Transit Data Archives

Transit agencies generally got a later start deploying intelligent transportation systems than their highway counterparts. TCRP Reports 113 (Using Archived AVL-APC Data to Improve Transit Performance and Management) and 126 (Leveraging ITS Data for Transit Market Research: A Practitioner's Guidebook) thoroughly document the value of AVL and APC data for transit agencies. In particular, AVL data help schedulers and service planners improve the quality of service delivered to the customer by producing empirical data that easily compares with scheduled service. At the same time, APC data help service planners understand trends in ridership and the productivity of the service being supplied.

In 2011, the National Center for Transit Research at the University of South Florida reported on the development of a prototype application to spatially visualize APC data using GTFS (*4*). The application supported analysis by route, trip and stop and offered as variables activity (ons, offs) and load. Although the prototype is still online (http://ridership.transitgis.org/) it is no longer active. Beyond that effort, however, there is no evidence of web-based transit data archives, especially with interactive, geo-spatial functionality.

METHODOLOGY

Initially, the team used ArcGIS to create data visualizations for selected sample areas to serve as proofs of concept. An original ArcPy script divides the GTFS shape data into stop segments containing associated segment metadata, including route and stop information. These segments are then dissolved to each other to create geometries appropriate for cartographic representation and display. Both sets of geometries are then loaded into a PostgreSQL database where various aggregate queries can be performed over any available attributes, such as time of day.

The major challenge for implementing this archive was integrating performance data from TriMet's passenger census with spatial data from the general transit feed specification (GTFS). This section describes how the research team accomplished this data management task as a prerequisite to building an interactive, online application.

TriMet's Passenger Census

TriMet employs a fleet of 625 buses, 127 light rail vehicles and six commuter rail vehicles to serve 318,500 average weekday trips(*5*). TriMet's entire bus fleet is equipped with both automated passenger counters (APC) and computer aided dispatch/automated vehicle location (CAD/AVL) technology. In addition 39% of the light rail fleet is equipped with APCs.

TriMet's bus dispatch system creates a database record every time a bus or train makes a service stop. The APC records the number of ons and offs and the CAD/AVL records the position and time. Other attributes, such as vehicle load and on-time performance, can be calculated from these empirical data. For example, TriMet defines "on-time" as between one minute early and five-minutes late of the scheduled stop time.

Table 1 displays an excerpt from TriMet's quarterly passenger census (with five rows, a subset of columns and truncated values). This illustrates how each record (row) represents a scheduled stop ("stop_time") at a specific location ("location_id"). Three fields (early, on_time and late) represent percentages and should sum to 1.0 and the "seconds_late" field can be positive (late) or negative (early). The field "estimated_load" represents a computation of ridership on a bus departing from that station stop.

For example, the data in table 1 show that a bus stopping at 4:56:51 AM at stop 1299 arrived, on average 44.5 seconds after the scheduled stop time during this quarter and had an average on-time rate of 82%. TriMet defines "on time" as an arrival between one minute before and four minutes after the scheduled time.

Table 1 Sample Data from TriMet's Quarterly Passenger Census

STOP_TIME	LOCATION_ID	ONS	OFFS	ESTIMATED_LOAD	EARLY	ON_TIME	LATE	SECONDS_LATE
4:56:51 am	1299	0	0	12	0.09091	0.81818	0.09090	44.54545
4:57:24 am	3489	0.54436	0	12.57142	0	1	0	67.09090
4:58:00 am	3506	2.72180	0.54436	15	0	0.83333	0.16666	109.41666
4:59:12 am	3451	0.13609	0	15.14285	0	1	0	83.16666
4:59:40 am	90	0.54436	0.68045	15	0	1	0	87.5

TriMet staff deliver a monthly performance report to the General Manager and Board of Directors, mainly in the form of a memorandum that describes notable trends in the consumption of service. The memo includes two tables: "system ridership summary" (excerpted below) and "key indicator performance report," both of which emphasize year-over-year changes. TriMet also produces graphs of this data on its website. Although TriMet's analysis team provides numerous detailed performance reports, the agency has sought to visualize the data spatially in order to enable better decision-making.

SYSTEM RIDERSHIP SUMMARY						
Measure	**May 13**	**May 12**	**% Change**	**FY13**	**FY12**	**% Change**
Avg Weekday Boardings						
Fixed Route						
Bus-Other Service	92,600	90,900	1.9%	91,691	85,290	7.5%
Bus-Frequent Service*	104,000	114,300	-9.0%	102,955	108,540	-5.1%
Subtotal All Bus	196,600	205,200	-4.2%	194,645	193,830	0.4%
MAX	122,800	134,200	-8.5%	120,764	129,830	-7.0%
Commuter Rail	1,800	1,750	2.9%	1,730	1,630	6.1%
Fixed Route Total	321,200	341,200	-5.9%	317,139	325,290	-2.5%
Paratransit						
LIFT& Cabs	3,693	3,550	4.0%	3,557	3,610	-1.5%
System Total	**324,893**	**344,700**	**-5.7%**	**320,696**	**328,900**	**-2.5%**

FIGURE 1 Excerpt from TriMet's May 2013 System Ridership Summary.

Spatially, the passenger census data are linked to unique stop identification numbers that have unambiguous geographic attributes (latitude and longitude). Mapping of the routes, however, is only done and maintained at a level of accuracy necessary for public information, which is not precise enough for performance analysis. In the first phase of this research project, we successfully mapped station-level data from the passenger census but failed in our attempts to map segment-level data because of problems with the existing shape files.

Mapping with General Transit Feed Specification Data

TriMet has been a committed supporter of open data and formats. This is evidenced in their work with Google on GTFS. Developed by Google engineers, GTFS is explicitly not a standard but provides a widely-adopted format with which transit data can be used and shared. The most visible use has been by developers of mobile applications.

Catala and Wong, respectively, have discussed the benefits that transit agencies have enjoyed from the use of GTFS, especially in the area of service analysis(*4*, *6*). This is largely because of the spatial precision of GTFS data. In contrast to TriMet's shape files that are used for public information, the GTFS provides a level of spatial accuracy not available through other geographic datasets which are primarily intended for generalized graphic display and are not suitable for use in analysis.

Using GTFS data, the project's GIS team created a base map of the transit network that accurately merges overlapping routes. Because the passenger census organizes records by stop identification number (nodes in the network), segment-based variables are drawn from the origin stop of each link in the network. As previously noted, the major challenge here was identifying overlapping segments, where multiple bus or rail routes operate in the same right of way. In the example illustrated below, one bus is carrying two riders while the other is carrying four. Where they overlap, the mapping needs to represent the combined value of six. Because of the accuracy of the GTFS data, the length (distance) of each segment and sub-segment is known and can be used for performance calculations. Later in the process, the team made design choices about how to represent this kind of attribute with color and/or thickness of the line.

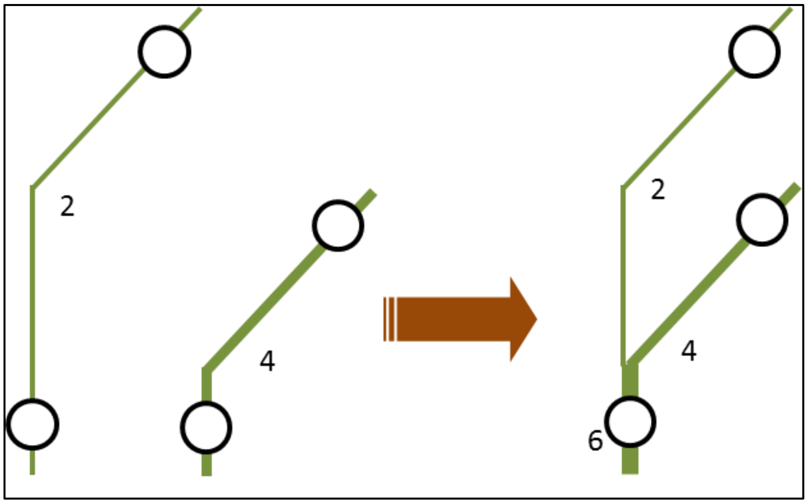

FIGURE 2 Mapping the transit network required a technique for merging overlapping route segments.

Designing Queries and Filters

Metrics

There is a significant literature on the myriad transit performance measures available based on sources such as APC and AVL data (*7,8,9)*. Berkow et al. described a variety of techniques for visualizing (spatially and otherwise) a one-year sample of TriMet's data (*10*). A group of stakeholders representing the region's transit agencies and MPOs recommended a core set of performance metrics to address in this project:

- Ons and offs at the stop level
- On-time performance at the stop level
- Load at the segment level
- Productivity (riders per mile) at the segment level
- Reliability (on time performance) at the segment level

Productivity is a very compelling measure to visualize geospatially, especially because of pervasive budget constraints in the industry. Productivity measures generally relate demand to supply. In the National Transit Database, for example, "Service Effectiveness" is calculated as unlinked passenger trips per vehicle revenue mile or hour. This is easy to calculate for a trip, route or entire system.

In our visualization of TriMet's GTFS and passenger census data, trips (boardings), revenue vehicle miles and passenger miles traveled are all feasible attributes of nodes or links (stops and segments) of the transit network map. Even where segments converge or diverge, as shown above in Figure 4, these attributes can be associated with sub-segments.

The unfortunate exception is time. When two routes converge, the distances associated with separate and overlapping sub-segments can be disaggregated but the travel time cannot, given existing technology on TriMet's fleet. Until or unless TriMet's AVL system can record time points other than those at stops, it is not possible to aggregate travel time across converging stop segments in the same way as distance. Without that ability, it is not possible to calculate measures such as productivity with time in the denominator.

Time-Based Analysis

TriMet's service types include weekday, Saturday, and Sunday/Holiday so the archive does not enable comparisons between individual days of the week. The data do support time-of-day querying, based on scheduled stop time. A user can customize a query window in 5-minute increments or select certain predefined windows (AM and PM peak).

Route-Based Analysis
The tool allows the user to select one or more routes for analysis. Although several routes may use a given segment or serve a given stop, a user may want to conduct analysis on a specific route.

Performance Standards
The tool is highly effective at supporting spatial analysis of TriMet's performance standards. For example, a user can observe all segments on which load exceeds a defined threshold or all stops at which service fails to reach a certain on-time percentage. This also means that a user can filter the data to show only stops with a certain level of ons or offs, or segments with a certain level of load or productivity.

RESULTS

Stop-Based Data

Mapping stop-based data is relatively straightforward because the passenger census records are unique to stop/station identification numbers (in both APC and GTFS data sets) and are easily represented by fixed points on the map. The APC records the number of passengers who get on and off the bus at each stop. When aggregated, TriMet calculates the quarterly (3-month) average of these values for each scheduled stop.

Boarding Activity
The management objective for this measure is to identify stops with the greatest level of total activity with some ability to understand how the activity is divided between passengers boarding and alighting. Because TriMet serves 6,800 bus stops and 85 light rail stops across 570 square miles, visualizing stop level data at a small scale limits the amount of visible detail.

As shown in the sample below, each stop is represented by a single dot, color coded to reflect the level of boarding activity at the stop during the morning weekday peak (7-9am). Because the passenger census records a quarterly average number of boardings, this map displays the 2-hour sum of average boardings ("Total Average Ons") at each stop. At this scale (1:288,000), it is easy to recognize the density of activity in the urban core of the region.

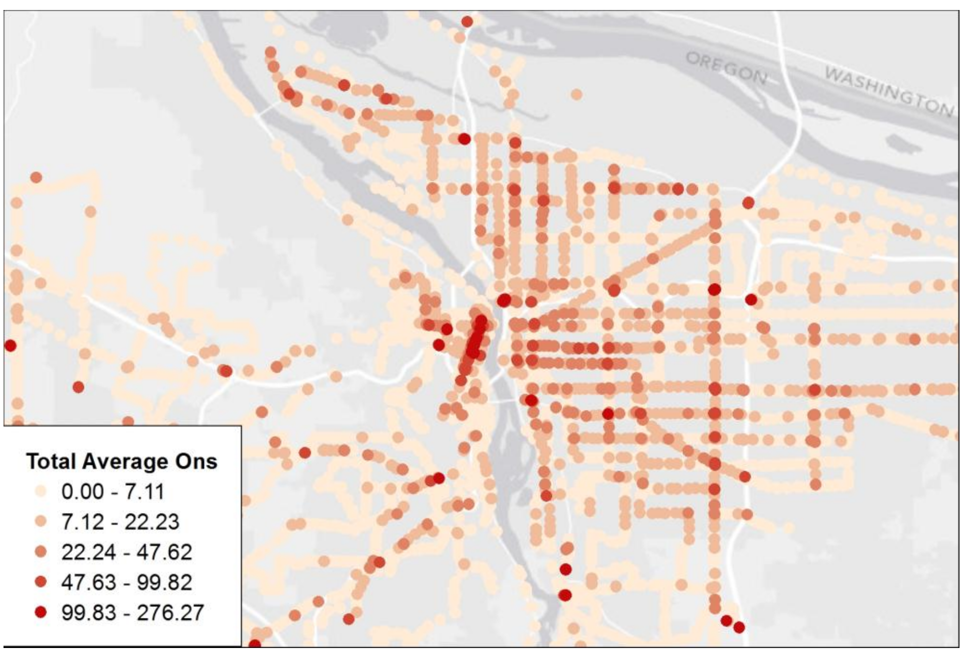

FIGURE 3 Small Scale Visualization of Transit Stop Activity Shows Density of Morning Peak Boardings in the Urban Core of the Portland, Oregon Metropolitan Area.

At a much larger scale (1:9,000), however, there is enough space between the stops to provide significantly more detail. Now, a pie chart replaces the color coded dot. The size of the pie chart represents the level of total activity at the stop (ons and offs) and the pie is divided into green and red slices to illustrate ons and offs, respectively. This enables the user to identify directional corridors, where the inbound stop is likely more green (ons) than red (offs) and the outbound stop across the street is the inverse.

FIGURE 4 Large Scale Visualization Allows Differentiation of Stop-Level Activity by Relationship of Boardings and Alightings During the Morning Peak.

On-Time Performance

The management objective for this measure has two functions, one of which has a strong orientation to customer service. Identifying stops/stations with poor on-time performance is a useful first-order diagnostic tool for service planning. In fact, the team considered attributing the on-time performance measure to the segment leading to a stop rather than to the stop itself. However, on-time performance is a very important measure with respect to how customers experience the system and that occurs as they wait for their bus or train at the stop/station.

At a larger scale, it is again possible to represent each stop with a pie chart. In this case, there is no change in the size of the pie and there are three subareas: green for on-time (between one minute early and four minutes late, according to TriMet), red for late and blue for early. This visualization enables one to see details of on-time performance at an individual stop, something that could be interesting to a transit user, an analyst or a manager.

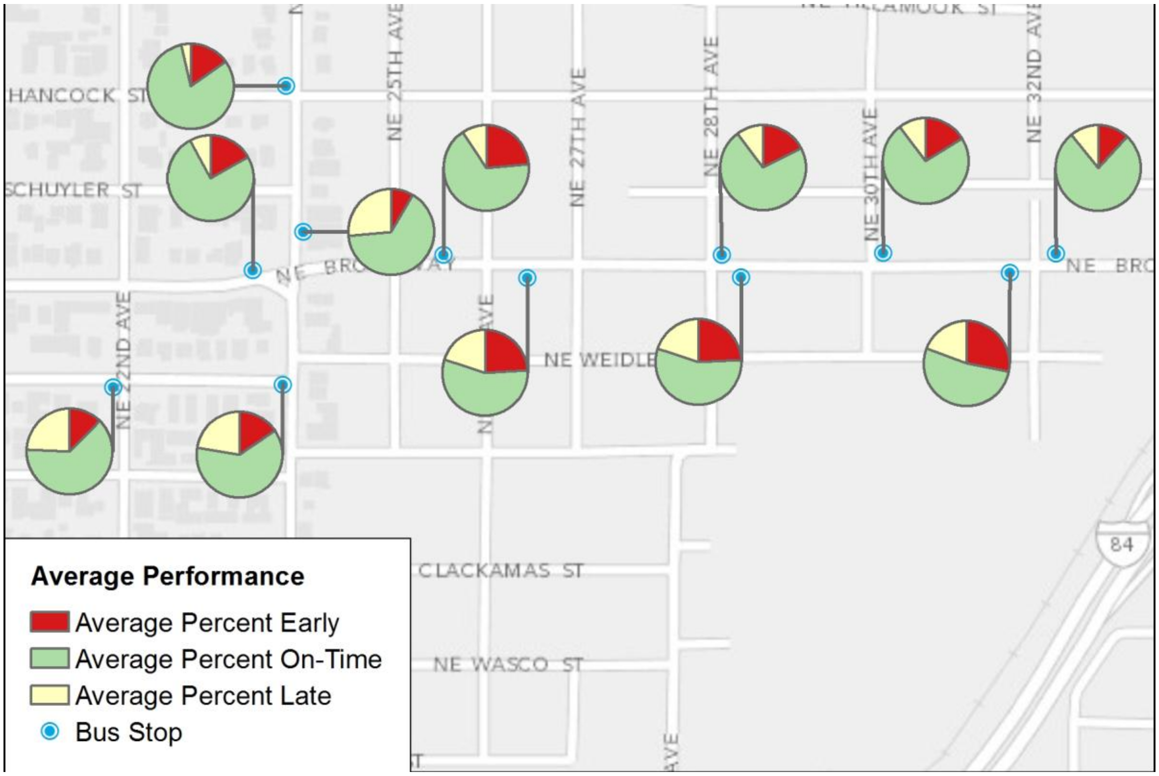

FIGURE 5 Large Scale Visualization Allows Differentiation of On-Time Performance by Early, On-Time and Late.

Segment-Based Data

Although TriMet's passenger census organizes records according to stop identification number, the database includes attributes that are more appropriately associated with segments. In some cases, there are measures that are important to the transit user at the stop-level but they are more relevant to the operator at the segment level, such as on-time performance. For the purposes of mapping, data fields that are assigned to nodes in the network can easily be assigned to either link adjacent to that node.

Passenger Loads

The management objective for this measure, in the tradition of the National Transit Database, is to visualize the total level of activity on the system. There are many examples of throughput maps in transportation. Annual Average Daily Traffic (AADT) is frequently mapped for local traffic impact analyses. Ton-Miles are often mapped nationally to illustrate volumes of freight traveling between major hubs such as Los Angeles and Chicago. Any kind of map of traffic load allows one to easily see how much travel activity is occurring in different parts of the system.

TriMet's passenger census includes the average departing load of the bus or train from each station/stop, which means we can assign that attribute (or another one, such as total stop activity) to the link adjacent to and immediately following the designated node. We considered representing this value with a color scheme and with thickness of the line. Although thickness is a common technique for volume, our conclusion was that a color scheme based on intensity more effectively communicated differences in passenger load across the system. In the figure below, one can see how the volume of travel activity increases as individual routes converge on their way towards a transit center or the central business district.

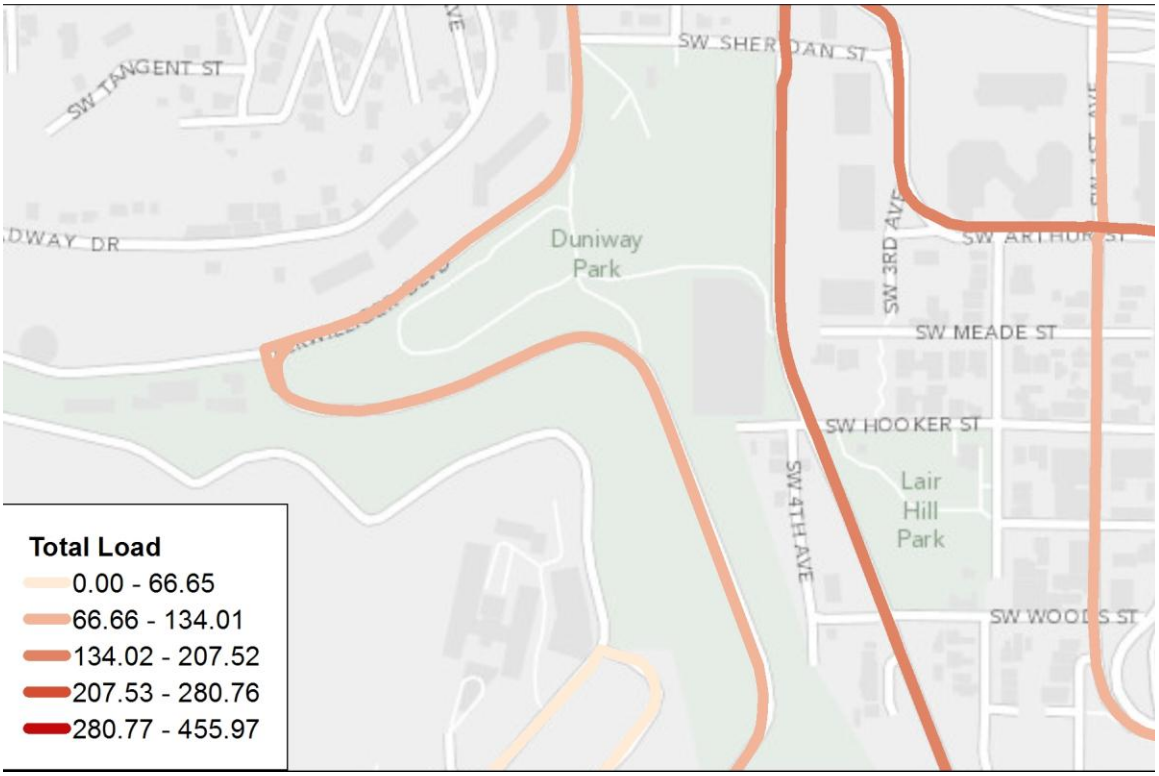

FIGURE 6 Large Scale Visualization of Passenger Loads Illustrates Low-Volume Tributary Routes Feeding High-Volume Arterials.

There are a number of other segment-based measures that we have not yet mapped. A close relation of passenger load would be vehicle occupancy. The passenger census includes seated and standing capacity in each record, making it very easy to calculate crowding.

Another possibility is to map reliability (on time performance) as an attribute of segments rather than stops. Although the transit user experiences reliability at the stop level, the operator is interested in identifying where a bus gets delayed along its run, especially if a location becomes a chronic source of service delay.

Building a Web-Based Application

For approximately ten years, Portland State University has housed Portal, an online archived data user service. Like many of its kind, Portal has housed only highway data for most of its existence. These data come of inductive loop detectors installed in more than one hundred locations around the Portland metropolitan area's freeway network. Volume, occupancy and speed data are collected from each detector and stored in the online database. The Portal website, *http://portal.its.pdx.edu*, offers several different interfaces through which a user can query, display and download these data.

The development of a transit data application represents a major change for Portal. The type of data is very different, the target audience is different and the types of queries users are likely to run on this new data type are different. What is fundamentally similar, however, is the objective of providing a simple and effective interface for the diverse users and purposes.

As a geospatial data archive, the principal feature is map-based navigation (see *http://portal.its.pdx.edu/Portal/index.php/transit*. Users begin their experience with a map of TriMet's three-county service area, with rivers and major highways as geographic points of reference. The user's first choice is to explore stop- or segment-based data. Within these categories, the user can select performance measures from a menu (activity and reliability at stops or load on segments).

There are several temporal ways to query the data. First, the user can define the time frame. Without restriction, the user can specify start and end times for the query. The user can also select predefined periods, such as AM and PM peak. The user can filter the data based on service type (weekday, weekend). Because of the way the passenger census is aggregated for each quarter, the user can select one or more quarters but cannot specify individual days of the week or specific dates from the calendar.

There are also several operational ways to query or filter the data. A user can filter by mode (bus, rail, or both) and by TriMet's frequent service designation, which indicates a maximum headway of 15 minutes. For the stop-based activity measure, the user can specify ons, offs, or both. Because every trip is designated as inbound or outbound, a user can filter based on directionality (this can be complex for non-radial routes). Importantly, the user can select one or more routes for the query.

DISCUSSION

The Prospect of Real Time Data

The signature quality of archived data user services is the storage of operational data that flows across networks in real time. By contrast, the application that we have created for archiving TriMet's passenger census and GTFS data relies on pre-screened, quality-controlled quarterly batches of data. This may represent an improvement over existing data handling and information dissemination practices at TriMet but it is still hardly comparable with the way Portal handles ODOT's loop detector data.

There are two primary obstacles to real-time archiving of APC data: technology and accuracy. With the existing technology, TriMet buses cannot transmit APC data en-route; the records are downloaded from the bus when it returns to the garage at the end of its service day. Therefore, TriMet has the technical ability to upload daily batches of APC data to Portal.

Quality is the more important concern. In a 2005 article in *Transportation Research Record*, Furth, Strathman and Hemily catalog the data quality challenges associated with APCs: errors associated with counting, location, trip attribution, modeling and sampling.(*10*) They cite an earlier article by Kimpel that found that bus type and the way counting sensors are installed can produce roughly 5% over-counting (*11).* TriMet has developed and implemented a consistent methodology for identifying and discarding erroneous records; that methodology has helped validate the reliability of APC data for reporting to the National Transit Database.

In fact, there are two issues at hand: the familiar question is whether it is possible to mitigate the various possible kinds of accuracy errors associated with APC data. This is relevant both to the National Transit Database and to the future of data archives, such as Portal. The other issue is whether TriMet could send data to Portal more frequently or at a lower level of aggregation, without compromising quality.

CONCLUSION

This paper has described an applied research initiative to create a web-based, geospatial transit performance data archive. The largest technical hurdle — creating the segments between stops and applying the attributes of point geometries — was overcome using a mix of open- and closed-source software. An interactive, map-based online data archive was successfully built.

Through this effort, this project demonstrated a replicable approach to integrating GTFS and performance data to support agency decision making. This represents a valuable manifestation of concepts that have been discussed extensively in the literature, including several TCRP reports.

Future work will expand the number of performance measures that can be mapped, both at stop and segment levels. The dual prospect of archiving quality-controlled data more frequently than quarterly and offering less aggregated data for querying remains a future prospect.

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