Mapping and Accessibility Analysis of Virginia Transit Systems

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Abstract—Growing demand for transportation in Virginia and a limited budget for public transit have led the Virginia Department of Rail and Public Transportation (VDRPT) to explore ways to improve the accessibility and related efficiencies of local bus systems. The effort described in this paper develops a prototype of a mapping analysis that can be used to assess the effectiveness of the Virginia bus system on a statewide level. A database and a mapping model is developed using Geographic Information Systems technology and is used to perform analysis of current transit accessibility. The creation of the map of bus stops involves the aggregation of stop location data from fifteen of the larger localities throughout Virginia. Using the mapping model, the overall effectiveness of the Virginia bus system is determined by calculating the total number of residents served by buses in the state. Population data are compared to funding and revenue levels by locality. The effort analyzes individual transit systems by assessing the proximity of bus stops to residential and commercial areas in individual transit systems. The analysis provides insight into comparing the efficiencies of the transit systems. The scope of the analysis may be expanded in future work to provide the VDRPT with a tool that can be used to increase overall transit efficiency and improve methods for allocation of funding.

I. INTRODUCTION

Currently the Commonwealth of Virginia has 44 local fixed-route transit systems served by buses. The Virginia Department of Rail and Public Transportation (VDRPT) wanted to develop a tool that could be used to evaluate the efficiency of all public bus systems operating in the state. In the context of this project, efficiency can be defined as the percentage of population served by buses and transit accessibility to key landmarks. The proposed solution involved creating a prototype mapping model backed by a database that could be used to assess the Virginia transit system as a whole.

GIS was used to create the prototype. GIS is a mapping software tool that enables the user to create many layers of data that can be used for geographic analysis. Past efforts have studied the use of GIS for accessibility and efficiency analysis of transit systems. [1,2,3,4,5,6,7,8] A number of the large bus systems operating in Virginia have been mapped using GIS. The localities that have implemented this technology use these maps both internally for analysis and externally as maps for the public. This project made use of the capability to map locations according to precise latitude and longitude coordinates in order to complete proximity analysis. Unfortunately, GIS data for transit systems throughout the state are managed by local transit organizations. While GIS is a helpful technology for individual localities, it is far more powerful when applied to an entire state. The project gathered and aggregated bus stop data, such as stop location, from transit organizations throughout Virginia in order to analyze efficiency on a statewide level. The methods of efficiency analysis developed throughout the project will facilitate the improvement and expansion of the bus system in the state of Virginia.

II. DATA COLLECTION

A. Obtaining Data

The effort first obtained existing GIS data from various sources. Transit organizations and planning district commissions provided the locations of stops for transit systems throughout the state. The fifteen largest systems were studied because they accounted for over 70 percent of total riders and 80 percent of total revenue for bus transit in 2005. [9] Year 2000 block level U.S. Census data were used in order to analysis population served by bus stops. This dataset was the most current data available for the level of exactness needed for the analysis. SNL Financial Provided the effort with the locations of all banks in Virginia. Analysis with bank data was used to approximate service to commercial areas because the effort wanted to provide the VDRPT with an idea of bus service to employment or commercial areas.

B. Preparing Data for Analysis

The effort needed to modify much of the data received because of computing constraints and accuracy of the data. Since a GIS data layer is made up of a map and an underlying geodatabase, database queries created in ArcMAP were used to modify the maps obtained for analysis. [10] Since the census data originally represented the entire country, it was cropped by selecting all data points whose value for the field “State_ID” corresponded to the state ID for Virginia in order to create a new layer of data comprised of only the specified points. All datasets contained unneeded data fields, which were also cropped using database queries.

The accuracy of bus stop data varied significantly, so the effort modified data before conducting analysis. Longitude and latitude coordinates were converted when given in the wrong format. Some information was provided in separate layers and had to be combined into a single layer of data using database join commands. Several systems provided the effort with GIS layers that contained undefined projections, meaning the bus stops would not be displayed in the correct location. Since these stops did not appear in the map of Virginia, they could not be used for analysis until the team projected the data into the state plane of Virginia.

Footnote: The Virginia Department of Rail and Public Transportation and the Virginia Transportation Research Council are the sponsors of this effort.
III. TOTAL POPULATION ANALYSIS

A. Methods

In order to analyze transit efficiency, all pertinent information was imported into the ArcMAP software interface. The data used included a layer representing bus stops and a layer containing block level population. Since the VDRPT wanted to determine the total percentage of the Virginia population served by buses, the effort needed to determine the total population served by each transit system. A database query that selected all population points within a quarter mile of any bus stop was created. This approach eliminated double counting of population and ensured an accurate computation. Figure 1 shows the total population analysis for the Falls Church Transit System, with population blocks shown as smaller, lighter points and transit service area represented by a polygon.

Fig. 1. Total Population Analysis for Falls Church local transit system

B. Results

A primary objective of the effort was to measure the current efficiency of the Virginia bus system as a whole. The most effective method of analysis was to compute the total number of residents living within a quarter mile of any bus stop. The analysis showed that 27.7 (1.96 mil) percent of the total Virginia population was served by the fifteen largest transit systems. Excluding the localities not served by these systems, buses served 40 percent of the targeted population. These figures provide the VDRPT with a general measure of coverage provided by the current transit system in Virginia.

IV. FUNDING, REVENUES, AND POPULATION ANALYSIS

A. Methods

Mr. Bill LaBaugh of the VDRPT shared 2005 statistics about revenue, operating costs, and ridership for each system. Being able to relate all three of these statistics with the number of people that live within a quarter-mile radius of a bus stop would provide a good general analysis. This would allow the VDRPT to specify what systems have low revenue, but have a lot of people living close to stops. Quickly recognizing these systems will identify what systems may need more or less funding.

Graphing these four variables directly onto a graph provides no value, since there is such a large range in the values. To eliminate this large range, while still keeping numbers meaning full, each number was normalized to a value between 0 and 1. The minimum number for each category was subtracted from each number. That number was then divided by the difference between the smallest and largest number in each category.[11]

\[ X_{normalized} = \frac{X_{original} - X_{min}}{X_{max} - X_{min}} \]  

(1)

B. Results

Spider graphs allow the VDRPT to quickly determine systems that are performing worse or better than others in different areas. In figure 2, this case, the Alexandria system has few riders and low revenue considering the number of residents that live within a quarter-mile radius of bus stops. Identifying these characteristics gives the VDRPT an opportunity to increase the funding, since there is a greater opportunity to increase ridership in the Alexandria area. If revenue is abnormally high relative to either operating cost or citizens served, that system could then be studied to determine how they effectively run the system. By comparing systems within Virginia according to several different variables, the VDRPT will be able to complete more complete method for determining funding allocation.

Fig. 2. Performance indices for the Alexandria local transit system

V. TRANSIT STOPS AND POPULATION ANALYSIS

A. Methods

All additional analysis was conducted on the efficiency of individual stops. The first step of this process involved defining the service zone of each stop. ArcMAP was used to create a quarter mile buffer around each bus stop. This technique caused some population and landmark points to be counted by several different bus stops, but also allowed the team to compute statistics such as average population served individual stops. An example of individual buffers around stops can be seen in Figure 3. Stops are shown as the large black points and population blocks are displayed as the smaller, light colored points.
After individual buffers were created for each stop, a series of database join commands enabled further analysis. Initially, population data and bus stop buffers were joined. This command created a database with an entry for each bus stop showing the number of households and residents within a quarter mile of the stop. Next, landmark databases were joined with the bus stop buffers, showing the number of banks and schools served by each stop. Finally, a join command was used to integrate all resulting databases. The last step provided all population and landmark data for each stop in one table. The final table could be used to conduct analysis on many variables simultaneously. Statistical software packages, such as MiniTab and Excel, were used to conduct system analysis using the final output table compiled using ArcMAP software.

B. Results

The effort yielded several notable conclusions. First, the analysis offered basic insight of the efficiency of current individual transit systems. The histograms used to evaluate population served by buses showed that the majority of transit systems had a high number of stops serving zero residents. Of the fifteen major transit systems, only Lynchburg, Charlottesville, Danville, Fairfax, Richmond, and Hampton Roads had their highest frequency for population served in a non-zero bin. Figure 4 shows an example of a system with a high incidence of stops serving few people.

Although Harrisonburg has many stops that serve a small amount of residents, the system is not necessarily inefficient. The stops not serving population could be important for access to other areas, such as employment centers or schools. Further analysis must be completed to more thoroughly assess system efficiency.

VI. POPULATION AND BANKS ANALYSIS

A. Methods

The effort observed multiple variables of efficiency simultaneously in order to gain a more complete representation of transit performance. For this analysis, a layer containing the locations of all banks in Virginia was imported into ArcMAP. Bus stop buffers and bank data were joined in the same fashion as the methods described in the previous section. The outputs for population served and banks served were then combined using a table join based on the ‘Stop_ID’ attribute. The analysis yielded the banks and residents for each bus stop. The effort used scatterplots to represent the relationship between number of reachable banks and total amount of people served.

B. Results

The analysis comparing bank and population service using scatterplots showed a clear trend. Most transit routes display an inverse relationship between the number of residents and banks served. Since commercial and residential zones are usually separate, this conclusion appears to be logical. One exception was Lynchburg, in that it had numerous instances of stops serving a large number of residents and banks. Figure 5 shows the scatterplot comparing population and banks served for Lynchburg.

Although Lynchburg may help to serve as a guide for other transit systems hoping to improve their service to commercial and residential areas, it is difficult to determine whether the efficiency of the Lynchburg system in this area is attributed to the layout of the bus stops or is caused by the zoning in the locality itself. Lynchburg serves as an example of why future work is necessary to fully realize the potential of this type of analysis. The results of the analysis were used to draw basic conclusions about the effectiveness of transit systems, but the methods used can not be employed as the only tool to evaluate transit efficiency.
VII. CONCLUSION

The effort performed several types of analysis after the preparing the bus stop data. First, figures were generated for the total number of Virginia residents served by the fifteen largest transit systems and were used as an additional metric for funding allocation. The analysis focused on bus service to residents and to commercial zones, represented by banks, in individual localities. The results of the analysis gave the VDRPT basic measures of the efficiency of transit systems. Still, the methods used can not be interpreted to be a complete determinant of transit effectiveness, and future development of the project is needed in order to give the VDRPT a more powerful analytical tool.

This effort has created the foundation for a promising tool for VDRPT by compiling the most import data and demonstrating useful forms of analysis. As stated in earlier sections, the effort must be developed further to become a powerful tool for judging the efficiency of transit on a statewide level. Both the number of variables being analyzed and the number of systems included in the analysis should be increased so that the VDRPT can have a more accurate guide for improving transit systems and funding allocation.

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