Measuring Transit Connectivity using GTFS Data

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Motivation and Objective

Public transportation is essential for mobility of users especially in urban areas where transit connectivity plays a crucial role in achieving acceptable travel experience. A vital task of transit-operations planning is to improve transit connectivity \( (1) \). The complex nature of transit networks makes connectivity assessment a challenging task. Transit systems consist of different levels: stops, links, transit lines. A link in a multi-modal transit network is part of a transit line that serves a sequence of transit stops (nodes) and a stop can be served by different transit lines \( (2) \). These characteristics require a multilevel systematic approach to measure connectivity and estimate performance measures. Measures of transit connectivity can be useful for transportation planning agencies in several ways. First, connectivity can be used as a performance indicator for transit stops and/or routes in order to evaluate the overall system performance, allowing transportation agencies to rationalize public spending in transit accordingly. Second, in rural or suburban areas, where detailed information regarding transit ridership is not available, connectivity can be translated into a measure of performance for developing service delivery strategies. Third, the connectivity measure can assess the effectiveness and efficiency of a transit system to prioritize the nodes/links in a transit system, particularly in terms of emergency evacuation. Finally, transit connectivity measures offer transit users the potential to assess the quality of transit service.

The objective of this research is to develop a unique approach to measure transit connectivity that does not require transit ridership data and transit assignment models. The methodology incorporates a graph theoretical approach to determine the performance of large-scale multimodal transit networks by quantifying measures of connectivity at multiple levels such as transit stops, links and lines. A connectivity index is developed considering unique qualities of each transit line and stop, such as location of nodes in terms of activity density, frequency at which each node is served, capacity of the transit line serving a node and speed of bus or rail serving the line when developing the connectivity index. The proposed methodology is applied (as a case study) in two urban areas to determine public transit connectivity of large multimodal transit system using General Transit Feed Specification (GTFS) data along with some demographic and socio-economic data. The new connectivity index significantly extends the set of performance analysis tools that decision-makers can use to assess the efficiency of the transit system.

Methodology

In the proposed formulation, transit node connectivity is estimated for a multimodal network consisting of transit lines of buses, light rail, bus rapid transit, and other similar transit facilities. We introduce the concept of connecting power of a node to: (1) represent how well a node (e.g. transit stop) serves in the scheme of a multimodal transit network, (2) identify the least, moderate and most connected nodes and (3) measure the performance of transit lines at a given node.

Node connectivity is defined as a function of connecting power of transit lines incident upon that node. The connecting power of a transit line is defined as the average of the inbound and outbound connecting powers since the connecting power may vary depending on the direction of travel. Details about how to determine connecting powers can be found in one of the previous publication by the authors \( (3) \). Inbound and outbound connecting powers of a transit line are a function of capacity, speed, activity and the distance that it serves. The formulation involves scaling coefficients which are indicators of attractiveness suggesting that higher the scaling coefficient values, more its attractiveness. The scaling
coefficients are also responsive in a very intuitive way. If one transit line becomes more attractive, for example, due to an increase in the number of operations during the day, the other transit lines become less attractive (on a comparison scale) and this change is reflected by the respective coefficients. A simple example will be presented later in this paper to demonstrate this concept.

Major Results

In this section, the numerical results obtained, using the proposed methodology, are presented along with some useful insights. GTFS data for Washington DC and Baltimore are used in study for numerical experiments. The transit database contained the two largest transit systems in the region, namely Washington D.C. Metropolitan Area Transit Authority (WMATA), and Maryland Transit Administration (MTA) in addition to a number of smaller transit agencies. GTFS data was converted to shape files using ArcGIS add-in toolbox¹ and the proposed connectivity algorithm is implemented using a R-script.

Node Level Connectivity

The Washington D.C. and Baltimore region have a significant number of transit nodes, each of which provide a varying degree of connectivity to the network. Figure 1 shows connectivity of Washington D.C. and Baltimore transit system at the node level, which is a function of connecting power of transit lines incident upon a given node. In this figure, range of color is used to represent node connectivity (red being least connected and green being well-connected) and height of the bars for relative comparison. From Figure 1(a), it can be noticed that, on one hand, there are some well-connected transit stops far away from the city center, and on the other hand, a significant number of poorly-connected stops can be seen in the region with highest concentration of transit stops. Similar observation can be drawn from Figure 1(b), which also shows a well-connected transit system with a few transit lines connecting a series of nodes with poor connectivity. This is an example of how capacity, speed, activity and the distance that a transit line serves are weighed in to provide a single connectivity index.

Line Level Connectivity

The line connectivity index is applied to the Washington D.C. and Baltimore transit system and Figure 2 exhibits the results obtained. In this figure, range of color is used to represent line connectivity (red being poor connectivity and green being high connectivity) and width of the lines for relative comparison. While concentration of highly connected lines at CBD is prominent, a significant number of low-connectivity transit lines are also serving the same region, as can be seen from Figure 2(a) and 2(b). The transit lines with high connecting power are mostly the metro lines in both the regions. Note that there are several transit lines providing high degree of connectivity to the suburban areas in Washington D.C. and Baltimore. Using the approach proposed in the paper transit agencies can estimate the connectivity of each transit line (also multiple line sharing portion of a larger transit path). Such line level connectivity will provide a measure of adequate, over or underutilized transit lines when interfaced with land use data to assist decision makers to better coordinate transit schedule, and routes.

Sensitivity to change in transit network characteristics

To demonstrate the sensitivity of the model with respect to the change in model parameters, specific routes are chosen and detailed analysis are not shown for the simplicity of visualization. For this analysis,

¹ http://www.arcgis.com/home/item.html?id=14189102b795412a85be5e1e09a0bafa
speed of Route 10A (serves between Huntington Point and Pentagon in Washington D.C.) is varied between 0-70 mph and percentage change in $\beta$ (scaling coefficient for “speed” parameter) is calculated for other routes in its vicinity. Figure 3 shows that, as speed of Route 10A increases the nearby routes lose their connecting power, to some extent consistently which are reflected by the negative change in connectivity parameter. For demonstration purposes here we show the effect for a single route. However, such type of sensitivity analysis can be performed for any line, node and resulting changes can be observed at transit network level.

Figure 1: Transit stop connectivity in Washington D.C. and Baltimore region.
Figure 2: Transit line connectivity
Implications for Practice in Travel Modeling

This paper proposed an approach to measure transit connectivity for large multimodal transit systems without requiring transit assignment models and extensive transit ridership data. The methodology is expected to be quite beneficial for transit agencies to estimate multimodal network connectivity and to capture the sensitivity when there is any change in the network characteristics. The graph theory based methodology analyzes properties of each transit node and line, and compares with the rest of the alternatives and proposes a connectivity score. The proposed approach provides disaggregate level connectivity measures without requiring detailed transit demand and transit assignment models.

This paper has multiple contributions in the area of transit connectivity. **First**, transit agencies can utilize multimodal transit connectivity of each node, line to determine most, moderate and least connected areas, and thereby decide to improve transit service to achieve higher transit ridership. **Second**, the proposed connectivity index can be used as an efficient quantitative measure of transit performance than the traditional measures such as degree centrality and betweenness centrality. **Third**, this approach efficiently captures sensitivity of the connectivity index to certain parameters (speed, capacity, frequency etc.) by assessing the change in attractiveness of transit lines or nodes. **Fourth**, the use of GTFS data in the proposed approach enables any planning agencies to adapt such procedure and obtain transit connectivity measures. Future research can include transit connectivity estimation in case of emergency evacuation to provide alternative transit routing information such that transit system can be fully utilized in serving transit captive riders.
References

