Spatial Analysis of Influences on Ridership on the Hiawatha Light Rail Transit System in the Minneapolis/St. Paul Metropolitan Area

Michael R. Jones
Department of Resource Analysis, Saint Mary's University of Minnesota, Minneapolis, MN 55404

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Abstract

In the United States, Light Rail Transit (LRT) systems have become a popular transportation alternative. Minnesota built its first light rail system in 2004 with the Hiawatha Line and additional projects are underway in the Minneapolis and St. Paul area. While light rail systems are attractive to commuters, they are expensive to construct and careful planning is ongoing to ensure their effectiveness. Analysis of ridership trends for LRT systems aid planners in optimizing the service area while operating within budgetary constraints. Two commonly accepted influences on transit use are: walking distance for access to transit, and population density within access areas. Using data from a survey of transit users in the Minneapolis/St. Paul metropolitan area, these two commonly accepted factors were analyzed to determine their significance in predicting ridership for the Hiawatha LRT. The analysis was carried out using ESRI GIS software and SPSS, a statistical analysis program.

Introduction

Light Rail Transit (LRT) systems have historically, as well as recently, been used in the United States (Kuby, Barranda, Upchurch, 2004). The positive perception of LRT, as a means to negate congestion and air quality issues associated with a high volume of vehicle traffic, has led to an increase in LRT system implementation in the United States (Kuby *et al.*, 2004). Between the periods of 1980-2003, twelve U.S. cities built LRT systems and twenty additional systems were being planned—including the Hiawatha Line in the Minneapolis area (Kuby *et al.*, 2004).

LRT is like other forms of rail transit, such as subway systems, in that LRT is composed of vehicles known as "cars", which are propelled by electricity over a two-rail track (Loetterle, 2001).

According to Loetterle (2001), LRT is capable of carrying more passengers than bus transit systems or streetcars but less than subways or commuter-rail systems, and is therefore considered a "medium-capacity" transit system. LRT systems primarily operate separate from streets, enabling them to avoid congested roadway systems, although tracks can be placed across from or embedded within streets in urban areas (Loetterle).

The first Minneapolis-area LRT, the Hiawatha Line, began operation in 2004. The Hiawatha line is twelve miles long and connects the Minneapolis/St. Paul International Airport with downtown Minneapolis. The system includes twenty-seven cars, each capable of carrying 186 passengers, capable of reaching speeds of fifty-five miles per hour. According to the

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Metro Transit division of the Metropolitan Council in Minnesota, a regional planning agency in the Minneapolis metropolitan area, the Hiawatha Line carried 42.9 million riders in its first five years of operation. The Hiawatha Line averaged 25,000 riders per weekday in 2004 (Mack, 2008). The area of this study is the jurisdiction of the Metropolitan Council, which is the 7 county area surrounding the twin cities of Minneapolis and St. Paul, Minnesota (Figure 1 and Figure 2).

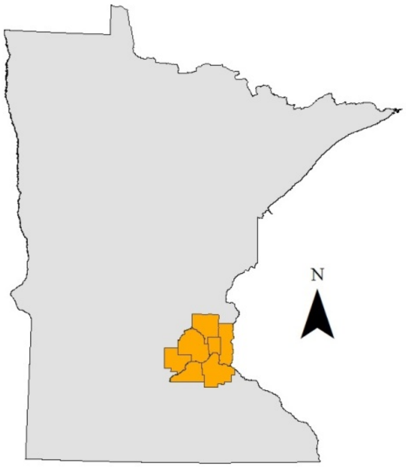

Figure 1. Seven Counties of the Minneapolis/St. Paul Metropolitan Area and their location in the State of Minnesota.

As this was the first LRT system to be built in Minnesota, planners had to study systems in other states to create a design for the Hiawatha Line. The primary focus of the design was to maximize the service area within the confines of the project area. As all transportation projects operate within budgetary constraints, it is necessary to optimize the effectiveness of the design. For these reasons, research is important in identifying key influences in LRT patronage.

A fundamental question posing planners is how to develop a comprehensive network of LRT lines that provide complete coverage of the Minneapolis and St. Paul metropolitan area (Loetterle, 2001).

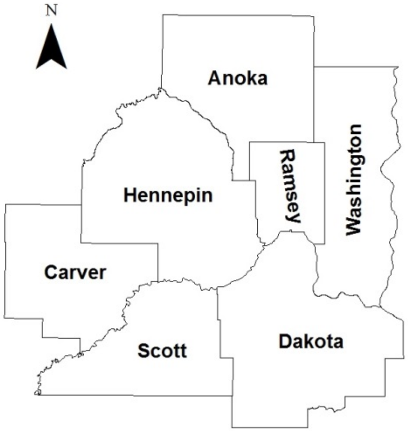

Figure 2. Seven county study area within the Minneapolis/St. Paul metropolitan Area.

In order to answer this question, Loetterle (2001) undertook a study in what drives ridership to an existing LRT line in Portland, Oregon. This study examined how the line serviced the surrounding neighborhoods to identify what defines the service area of a LRT system (Loetterle).

Transit planners have generally used a half-mile as the walking distance when planning for transit systems (Loetterle, 2001). Research by Loetterle suggests this rule is not accurate in defining the walking distance for planning of LRT. In other studies, evidence shows LRT riders were willing to walk farther than the industry standard (Kim, Ulfarsson, and Hennessy, 2007). In the Portland area, over thirty percent of commuters were willing to walk over a half-mile to use LRT (Loetterle). Kim *et al.* (2007) concluded the distance from a user's home to a LRT station will determine the likelihood of the user walking to that station; where the longer the distance, the less likely it is the user will walk. Loetterle (2001) concluded 90% of commuters who walked to LRT stations did so from less than one mile, and a half-mile to a mile would be considered a reasonable walking distance in planning for LRT. Kim *et al.* (2007) found LRT riders in St. Louis walked on average .47 mile to LRT stations.

Population density is also widely viewed as an important determinant in planning for LRT station location. Population density, particularly of a residential population, has been found to be statistically significant in statistical models in showing positive association with railway patronage (Loo, Chen, and Chan, 2010).

Future LRT projects in the Minneapolis/St. Paul metropolitan area are currently under development and additional projects are likely to occur. Studies aimed at analyzing trends in ridership of the Hiawatha Line will help in making better designs for future systems. Now that the Hiawatha system is operational, there is an opportunity to analyze trends in ridership and look for conformity to these known influences. Using the capabilities of GIS software, this analysis aims to examine the significance of walking distance and population density in influencing ridership on the Hiawatha LRT system.

Methods

Data Acquisition

The Metropolitan Council, a regional planning organization for the Minneapolis-St. Paul metro area, recently published the results of an on-board survey of transit riders. This survey was conducted in the fall of 2010 as part of a greater effort to create an inventory of travel behavior data for transportation modeling and forecasting (Generalized Land Use 2010, 2011). The information collected via the survey covered many aspects of travel behavior. Much of the information collected is pertinent to this study such as: rider origin, origin address, rider destination, travel mode to station, and transit system used. The survey results were published as a Microsoft Excel spreadsheet. A total of 22,349 survey responses were compiled into the published data set; with 3,003 responses from riders of the Hiawatha LRT system.

The Metropolitan Council’s website also serves as a repository for GIS data in the metro area. This website was used to obtain GIS feature data sets representing locations of the Hiawatha LRT infrastructure. Specifically, a shapefile with the locations of stations serving the Hiawatha LRT (Figure 3). The shapefile consists of point features for all 19 LRT stations.

U.S. Census data was used to create a data set for calculating population density. U.S. Census data is widely used by GIS professionals because of its comprehensiveness, general availability, and availability at multiple geographic scales. The census block aggregation level

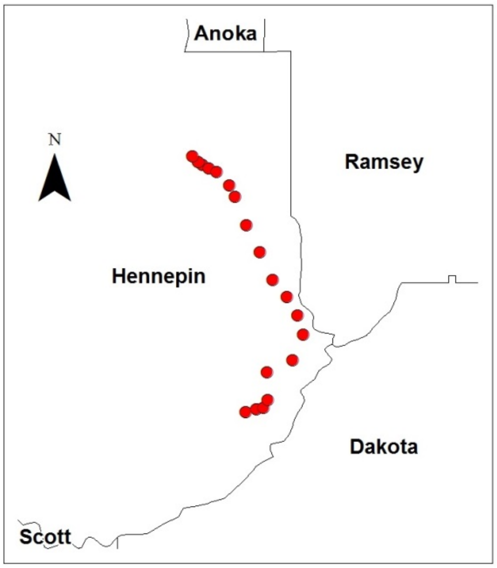

Figure 3. Location of Hiawatha LRT stations within the Minneapolis/St. Paul metropolitan Area. Red symbols represent LRT station locations.

was chosen for this study, as it is the smallest geographic unit of aggregation, and therefore provides the least amount of generalization of the data. All census data was obtained from the Metropolitan Council's GIS repository. A census TIGER/Line shapefile was downloaded along with the corresponding Summary File 1 (SF1) Population table for Census Blocks. The data provided population counts for the 7 counties within the metro area.

Due to the high degree of generalization associated with census aggregation levels, where populations are assumed to be dispersed evenly over an a area of varying land use/cover types, the population data was transformed during the creation of a population density data set. The transformation used ancillary data related to population dispersal and land use data to subdivide the areal units of aggregation. The results of this disaggregation process provided for a more accurate depiction of population density by using geographic units smaller than those provided by census blocks and more representative of true area of residence.

Land use data were obtained from the Metropolitan Council. The Generalized Land Use 2010 data set covers the entirety of the seven county metropolitan region. The areas outlined by land use class were used as a means of disaggregating the census data in a procedure described in the subsequent section.

Data Transformation

A subset of the transit rider survey was needed to extract the data pertaining to the Hiawatha LRT system. A series of queries were run to extract only results relevant for this study. The first query selected transit passengers using transit route 55, the Hiawatha Line. This subset contained 3,003 records. Next, passengers who accessed the transit system on foot were parsed into another subset which included 1,085 records. This subset was again parsed to select passengers originating from a residence. As population density is a primary metric of interest in the influence on LRT ridership, passengers not originating from a residence were eliminating to avoid skewing the data with low population density values coming from commercial or industrial areas. A final subset was created to eliminate any rider that accessed the LRT via transfer from another transit system such as a bus. The final subset of Hiawatha LRT riders consisted of 374 records.

Once the appropriate data were prepared from the ridership survey, the data was imported into a GIS for spatial analysis. A shapefile of LRT riders was created using the pre-populated fields containing geographic coordinates (Figure 4). The original survey data set included fields with geographic coordinates for rider origins and destinations – if addresses were provided for either category. The shapefile created contained 345 features. The discrepancy between the 345 features created in the shapefile and 374 records in the subset of surveyed passengers was due to missing address and coordinate information in the original survey data. Only the coordinate values for rider origin were used to create the shapefile, as access to the LRT system from the point of origin was what was being analyzed. This shapefile was then transformed into a UTM coordinate system, Zone 15 N, in order to ensure accuracy when calculating distances.

Distance Determination

A distance was calculated from each rider

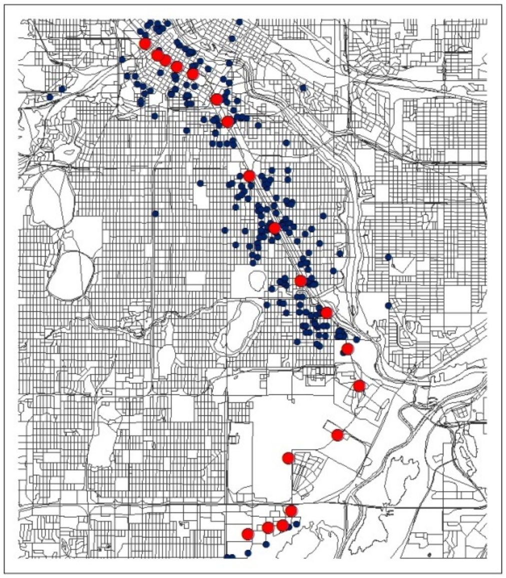

Figure 4. Locations of LRT rider origins in relation to LRT stations. The red symbols represent LRT stations and the blue symbols represent LRT rider origins. The boundaries displayed are census blocks.

origin to the nearest LRT station. This was accomplished within ESRI ArcMap using the NEAR distance calculation tool. The tool provided a measurement of the Euclidean distance, in miles, from a point of rider origin to the nearest station point in the LRT stations shapefile. The calculated values were added to a new field in the LRT rider shapefile.

Population Density Determination

Transformation of the census population data was done to disaggregate the total population at the census block level and redistribute the population values into smaller areas of land use. Again, this was done to increase the accuracy of the population density calculations by using geographic units more representative of actual population locations. Census blocks are areas bound by visible features such as streets, roads, streams; and invisible boundaries such as city or county limits (Mennis, 2003). The disaggregation method employs the principles of dasymetirc mapping, where quantifiable areal data is depicted using boundaries of relative homogeneity directly related to the function of the map (Mennis). For the purpose of this study, the variations in population density amongst land use zones were used to redistribute the population values.

The method chosen for the disaggregation of census data was a variation of the methodology used by Mennis (2003) for dasymetric mapping using surface models. However, rather than interpolating the population values into a continuous surface model, which is the final process in the methodology used by Mennis, this procedure only created zones of homogenous area using an ancillary data source related to population – which is land use. The Generalized Land Use 2010 shapefile was used as the ancillary data source for this purpose. This procedure was deemed appropriate since the interpolation in creating a surface model negates the preservation of total population values when population is re-aggregated at the original census block boundaries. Thus, by maintaining population values consistent with those at the census block level, the data maintains the accuracy of the original census data.

The land use zones were created in ArcMap using the Census TIGER/SF1 and Generalized Land Use 2010 data. The boundaries of TIGER/Line Census blocks were used to split the Generalized Land Use 2010 features into areas of land use within each block. The features produced contained attributes for both intersecting layers. These new land use zones were then analyzed to determine how the total population value for the census block should be redistributed.

Analyzing the land use zones began by first calculating the proportion of the different land uses within each census block. This was accomplished by dividing the area of the LU zone by the total area of the census block it resides in. Next, the land use designations from the Generalized Land Use 2010 were reclassified into 3 groups based on a sampling of total population for each LU type following the methodology described by Mennis (2003). First, all land use zones comprising the entirety of, or the near entirety of, a census block were selected for sampling. The sample consisted of any land use zone with a proportion greater than or equal to 90%. The 90% ratio was used in the selection since it resulted in a large sample size while only those land use zones that composed nearly all of the census block were included. The total population was then tallied for each land use type (Table 1). A new field was created in the land use zone shapefile and classifications were assigned based on the original LU designation.

A summary of total area and population was then derived for each of the three LU classes. The Dissolve tool was used to dissolve the land use zone features based on the value for LU classification. The resulting shapefile contained one feature for all land use zones of a particular LU classification (Figure 5).

The numeric values for total population and area were summarized in the dissolve process to give a sum total of their respective fields. The total population and area values were then used to calculate the “population density fraction” (Mennis, 2003) which was then used to determine what proportion of the census block population would be redistributed to the land use zones it contains. According to Mennis (2003), the population density fraction is “calculated by dividing an urbanization class’s population density by the sum of all population density values for all three urbanization classes.”

Table 1. Classification scheme for Land Use designations. Land use types are classified as: high, medium, and low residential based on mean population. All land use types not included in classification scheme are non-residential land use designations.

	Mean Pop	**Zone Count (>90% of Census Block)**
High-Density		
Mixed Use Residential	217	16
Multifamily	129	427
Medium-Density		
Single Family Detached	52	16,553
Single Family Attached	45	1,455
Institutional	24	793
Low-Density		
Retail & Other Commercial	1	931

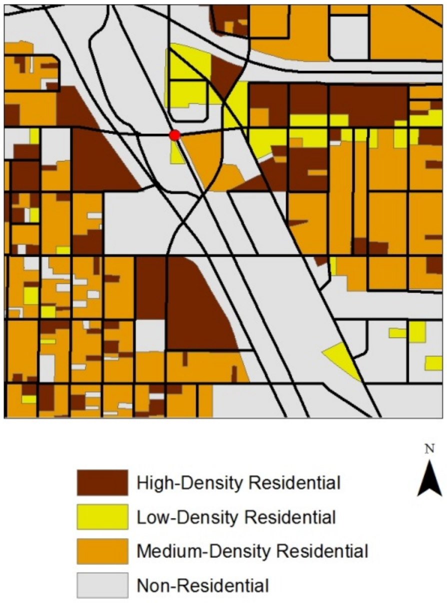

Figure 5. Land use classification zones within Census Block boundaries. Red symbol represents LRT station.

This calculation is shown below for each of the land use classes (Table 2). The values for population density fraction were joined to the land use zone shapefile based on the classification assigned to a feature.

Table 2. Population Density, in persons per 10,000 square meters, for each land use classification. The following equations show the Population Density Fraction calculations for each class.

	Total Area	Total Pop.	Pop. Density
High-Density	214,774	3,777	175.86
Medium-Density	3,122,444	8,267	26.5
Low-Density	461,795	115	2.5

High-Density: 175.86/204.86 = .86
Medium-Density: 26.5/204.86 = .13
Low-Density: 2.5/204.86 = .01

The population density fraction was calculated to determine the average population density associated with each LU classification. The proportion of area occupied by each LU class within a census block was taken into consideration. This difference in proportions was factored in using the “area ratio” defined by Mennis (2003) as the “ratio of the percentage of area that an urbanization class actually occupies within a block group (block) to the expected percentage…”. The “expected” percentage being the percentage of the block divided evenly among the number of land use zones within it. For instance, 33.3% would be the expected percentage if three zones exist within a block.

$$\textbf{Area Ratio} = (a_{cb}/a_b) / (1 / n_{cb})$$

Area Ration Equation. Where a_{cb}= the area of land use class c in census block , a_b = the area of census block b, and n_{cb}= number of land use classes c present in census block b (Mennis, 2003).

The Total Fraction that was used to redistribute census block population to a land use zone, based on the LU classification and proportion of area within the block was then calculated. The Total Fraction was derived by “multiplying the Population Density Fraction and Area Ratio of a given urbanization class in a given block group [block] and dividing the result by the result for all three urbanization classes in that block group [block]” (Mennis, 2003).

The last operation was to multiply the Total Fraction for each land use zone with the total population of the census block in which it occurred. The culmination of these operations was the population value for each feature in the land use zone shapefile. A population density field was then created by dividing the newly derived land use zone population by the area of the land use zone (Figure 6).

Analysis

Distance Analysis

When distance measurements were analyzed, several seemingly unusual results were noted. A small number of geo-referenced rider origins occurred at great distances from LRT stations; up to 28 miles away. Outliers such as these were likely due to errors in responding to survey questions, misunderstanding the questions in the survey, or errors in processing the survey results. No matter the case, these events indicated some additional filtering was needed to remove the erroneous data. In order to remove all events that were unlikely to have occurred and would otherwise skew the data set, the distance calculations of origin to station were sorted in ascending order and the first 95% of riders were included.

The maximum distance within the selection was 3 miles. Any feature with a distance of origin existing over 3 miles was then removed from the study. A total of 15 riders were excluded based on this constraint.

Figure 6. Land use zones displayed by population density. Population density measured in people per 10,000 m². Red symbol represents LRT station.

Of the 252 riders included in the study, all walking a distance of no greater than three miles to access the LRT, 187, or 74%, traveled less than .5 miles. A total of 243 riders, or 96%, traveled a distance no more than 1 mile. Only one rider was found to have traveled over 2 miles; this rider traveled a distance of 2.6 miles. The descriptive statistics of rider origin distance are show in Table 3. Riders were then linked to the land use zone shapefile through a spatial join in order to determine a count of riders per zone. The count of point features, representing riders, within each land use zone polygon was tallied. An additional field was calculated during the spatial join to sum the rider origin distances for all points within a zone. This sum of origin distances was then divided by the count of rider origins in order to calculate the mean rider origin distance for each zone.

Table 3. Descriptive statistics of rider origin distance. Sample includes LRT riders originating within 3 miles of an LRT station and accessing the LRT system on foot.

N	252.00
Min	.25
Max	2.58
Mean	.41

Of the 191 land use zones containing at least one LRT rider, 133, or 70%, had a centroid within .5 miles of an LRT station. A total of 181 zones out of 191, or 95%, had a centroid within 1 mile of an LRT station. Only two zones had a centroid beyond 2 miles of a station; at distances of 2.05 and 2.5 miles (Table 4).

Table 4. Descriptive statistics of distance from LU zone centroids to nearest LRT station. Sample includes LU zones containing origins of LRT riders within 3 miles of a station.

N	191.00
Min	.02
Max	2.58
Mean	.45

Population Density Analysis

Of the 191 land use zones with LRT rider origins, the mean area was 34,630 square meters. The smallest zone had an area of around 50 m², and the largest zone had an area of over 2 million square meters. However, the largest zone should be considered an outlier as its size was well outside two standard deviations of the mean area. It should also be noted that this zone exists in an extraordinary geographic area, the Minnesota Valley National Wildlife Refuge. The descriptive statistics describing the land use zones in relation to population and LRT ridership are shown below in Table 5 and Table 6.

Table 5. Descriptive statistics of population density within LU zones. Population density measured in ppl/10k m^2.

N	**191.00**
Min	.003
Max	651.29
Mean	80.77

Table 6. Descriptive statistics of the number of rider origins, "rider count," within LU zones.

N	**191.00**
Min	1.00
Max	7.00
Mean	1.33

Regression Analysis

A generalized linear regression model was used to analyze the relationship of population density and origin distance with LRT ridership. A Poisson regression was chosen as the type of generalized linear model based on the characteristics of the data. As the LRT ridership variable, the number of riders per land use zone, is measured as a count, the Poisson distribution was chosen as it is a distribution that "takes on a probability value only for nonnegative integers…making it an excellent choice for modeling count outcomes" (Coxe, 2009).

As count outcomes are measures of discrete rare events, the assumptions of many linear regression models are violated. A linear regression using OLS, for example, would not account for the heteroscedasticity of a count variable, where count data will often show an increase in conditional variance with an increase in the value of the predictor variable (Coxe, 2009). Also, the skewedness resulting from a majority of counts having a low value would violate the assumptions of normality and the conditionally normal error structure associated with OLS regression.

The Poisson regression is a type of generalized linear regression that uses the error structure of the Poisson distribution. The natural log link function of a generalized linear model, and the flexible error structure of the Poisson distribution, allow the Poisson regression model to "resolve the major problems with applying the OLS regression to count outcomes, namely, nonconstant variance of the errors and non-normal conditional distribution of errors" (Coxe, 2009).

The Poisson regression model was run using IBM SPSS statistical software. The rider count per land use zone was used as the dependent variable in the model with the 'mean distance of origin' and 'population density' serving as predictor variables.

Descriptive statistics of the model show 191 observations were included for each variable – consistent with the 191 land use zones produced in the spatial analysis. These statistics are notably similar to the descriptive statistics observed early in the spatial analysis carried out in ArcGIS. It is important to note that the mean and variance are similar for Rider Count. This is an assumption of the Poisson distribution. Descriptive statistics for all variables are shown below (Tables 7, 8, and 9).

Results

Results of the regression analysis show there is a statistical significance for predicting Hiawatha LRT ridership using the predictor variables. The Omnibus Test

(Table 10) compares the fitted model, regression of rider counts with predictor variables, against the “intercept-only” model, which has no predictor variables. The Omnibus Test is then a measure of significance of adding the predictor variables to the intercept-only model. According the Omnibus test statistic, .030, the fitted model is statistically significant.

Table 7. Descriptive statistics of dependent variable, Rider Count.

N	191.00
Min	1.00
Max	7.00
Mean	1.32
Var	.57

Table 8. Descriptive statistics of covariate, Population Density.

N	191.00
Min	.003
Max	651.289
Mean	80.774

Table 9. Descriptive statistics of covariate, Rider Origin Distance.

N	191.00
Min	.020
Max	2.579
Mean	.457

Table 10. Omnibus Test results.

Likelihood ratio Chi Square	df	Sig.
7.000	2	.030

The Test of Model Effects (Table 11) shows a statistical significance for the variable, Mean Origin Distance, with a test statistic of .001. According to this result, mean distance of origin is highly significant in explaining the variance in the number of riders originating from a land use zone. The variable for population density, Pop Dens, is just beyond the significance level at .070. Therefore, it cannot be statistically said that population density is a significant predictor for the number of riders originating from a land use zone. However, with the test statistic so near the significance level of .05, this variable does appear to be important in predicting ridership.

Table 11. Tests of Model Effects results.

Source	Wald Chi-Square	df	Sig.
(Intercept)	22.121	1	.000
Pop Dens	3.284	1	.070
Mean Origin Dist.	10.325	1	.001

According to the Parameter Estimates table (Table 12), the coefficient for distance of origin is -.503. Therefore, a one unit increase in distance of origin would result in a .5 decrease in log rider count. The log value comes from the natural log transformation of count data via the Poisson regression. In order to interpret the coefficient as it applies to the original count data, instead of the log transformed count, the exponentiation of the coefficient is used (Coxe, 2009). As shown in Table 12, the exponentiation of the coefficient, Exp(β), for mean origin distance is .605.

Table 12. Parameter Estimates results.

Parameter	β	Std. Error	Exp(β)
(Intercept)	.442	.0930	1.555
Pop Dens	.001	.0004	1.001
Mean Origin Dist.	-.503	.1564	.605

This is interpreted as a 1-unit change in mean distance origin resulting in .605 times as many riders per land use zone. The coefficient for population density was not found to be statistically significant (p > .05).

Conclusions

The results of this study show one of the most widely considered influences on transit ridership – pedestrian travel to station – does have a significant influence on riders of the Hiawatha light-rail transit system. This result can serve to reinforce planning methods oriented to pedestrian service with future LRT development. As an increasing emphasis is placed on providing transportation alternatives to single-occupancy vehicles within metropolitan areas, this study shows the importance of pedestrian access.

Interestingly, population density, another widely associated influence of transit ridership, was found to be insignificant in predicting ridership counts. As it would seem to be intuitive that areas of high residential concentration would produce an increase in transit ridership, this result is the most intriguing. Given that the test statistic for population density was near the significance level, perhaps additional modeling with a modified model would determine a different result. Additional modeling of other demographic characteristics could also serve to be valuable in further describing the ridership trends of LRT riders.

The dasymetric method for deriving population density from Census block features could also serve to be a valuable component of future research. The concepts described in this methodology could also be applied to other demographic characteristics represented in census data. Also, the success of the method validates the importance of GIS data production for regional planning uses, such as the Generalized Land Use 2010 data.

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