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RICHMOND'S JOURNEY-TO-WORK TRANSIT TRIP-MAKING ANALYSIS

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Abstract
This paper uses the 2000 Census Transportation Planning Package data to conduct a journey-to-work transit trip-making analysis for the City of Richmond, Virginia. In spite of its low modal share, transit is critical to the City due to its unique demographics and high transit demand. Findings of statistical analyses suggest that factors impacting transit uses at place-of-residence and place-of-work are different. Nevertheless, they share one thing in common that it is essential to improve transit accessibility to workers, especially the ones whose households are below poverty status. The existing hub-and-spoke bus transit system is being challenged by the City's suburbanization movement and declining downtown area. To accommodate this trend and unmet transit needs, this paper recommends strengthening the bus transit services in the urban fringe residential areas, rather than exclusively focusing on the suburb-downtown transit improvements.

Keywords: Public transportation; Social factors; Ridership; Urban areas

1. INTRODUCTION

Richmond is the capital city of the Commonwealth of Virginia with a long history dating back to the early 17th century. Richmond and its surrounding counties (Hanover County, Henrico County, Town of Ashland, City of Richmond, a majority of Chesterfield County, portions of Charles City County, Goochland County, New Kent County, and Powhatan County) form the Richmond metropolitan region (Figure 1), which had a total population of 822,416 and a total employment of 617,578 in year 2000.

Though being touted as the first U.S. city with an electric trolley-powered streetcars operating during 1888-1949, Richmond is currently facing a challenge in its bus-dominated transit system operation. Among others, the following issues seem evident: increasing incompatibility of the existing hub-and-spoke transit network with the future travel pattern due to the on-going suburbanization movement (Figure 2), lack of transit services in some high transit-demand areas (Figure 3), absence of high-capacity transit facilities along key corridors, and limited funding/jurisdictional support for upgrading transit services. Because of these issues, the transit modal share has been declining in Richmond. According to the Richmond Regional Planning District Commission (2008), the number of commuters that drove alone to work rose from 78% modal share

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in 1990 to 82% modal share in 2000. In contrast, the percentage of public transit use declined from 4% in 1990 to 2% in 2000.

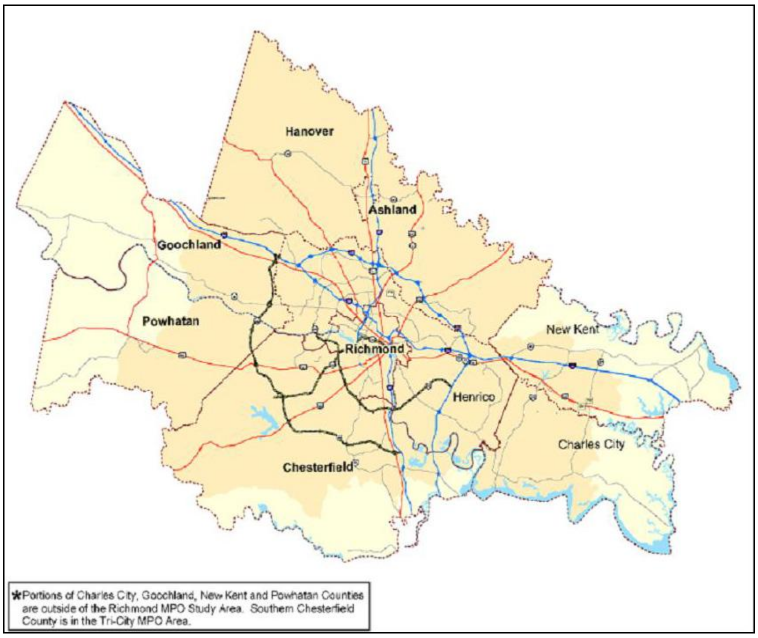

FIGURE 1 - MAP OF THE RICHMOND AREA METROPOLITAN PLANNING ORGANIZATION PLANNING AREA
Source: Richmond Regional Planning District Commission. (2008). *Richmond Area MPO 2031 Long-Range Transportation Plan*, Richmond, Virginia

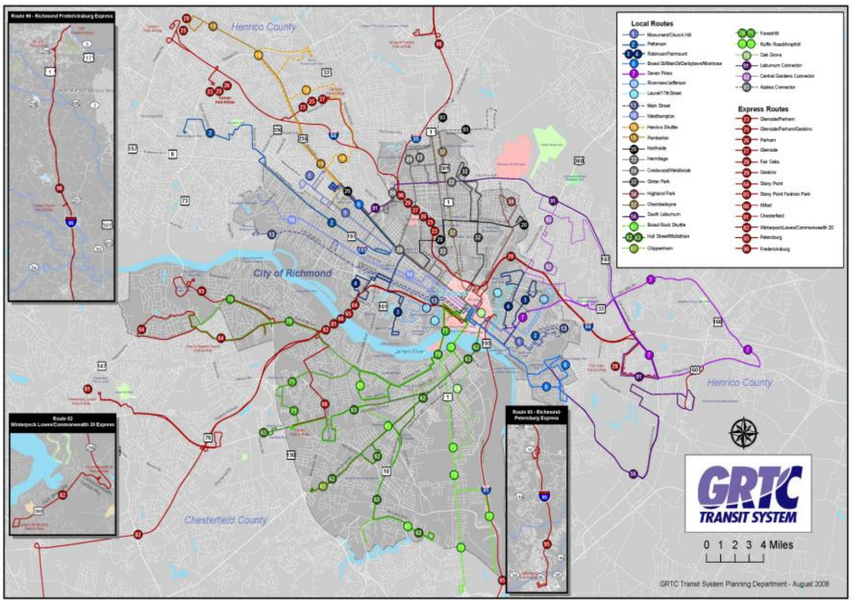

FIGURE 2 - GREATER RICHMOND TRANSIT COMPANY (GRTC) BUS ROUTE MAP
Source: Greater Richmond Transit Company. (2008). Comprehensive Operations Analysis, Richmond, Virginia

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2067- 2462

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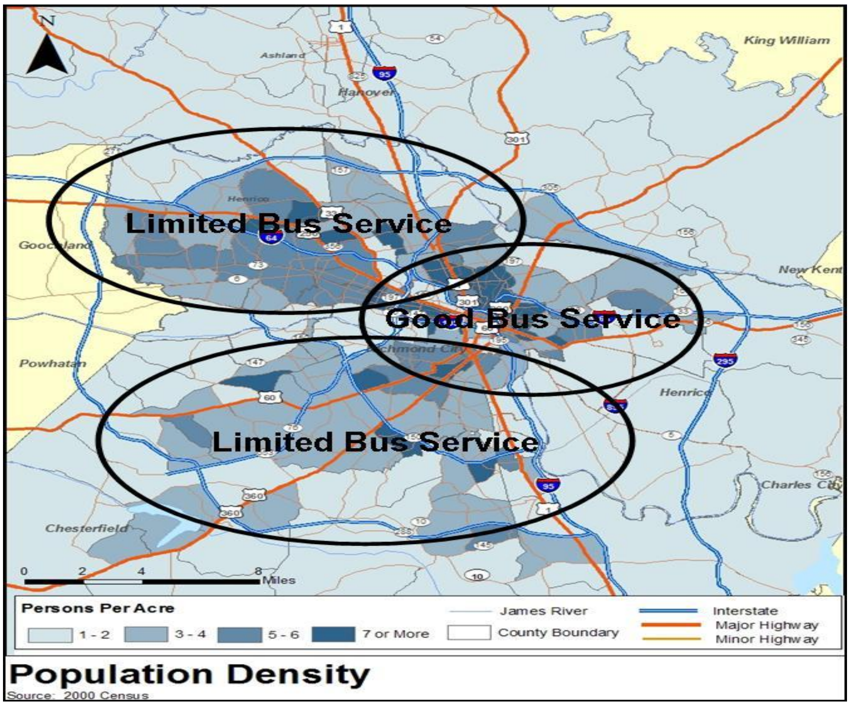

FIGURE 3 - BUS SERVICE AND POPULATION DENSITY
Source: Greater Richmond Transit Company. (2008). Comprehensive Operations Analysis, Richmond, Virginia

In order to deal with these issues, local transit and planning agencies recently prepared both short-range and long-range transit plans. For example, the Greater Richmond Transit Company (GRTC) completed its most recent update of the Comprehensive Operations Analysis (COA) in March 2008 with a list of service improvement recommendations ranging from optimizing bus routes, building transfer centers, and launching a bus rapid transit line along Broad Street. Based on GRTC's COA, the Richmond Regional Planning District Commission (RRPDC) also finished its final technical report of the Richmond Regional Mass Transit Study (RRMTS) in May 2008. Concurrently, RRPDC collaborated with the Urban and Regional Planning Program at Virginia Commonwealth University (VCU) and conducted transit-oriented development (TOD) studies along the region's key transportation corridors. All of the above plans include very detailed and comprehensive transit analyses based on their intensive surveys and data collection efforts. Because of that, they will surely guide Richmond's future transit planning.

The above studies identified a wide range of factors influencing residents' use of transit services. However, they fell short of identifying the most significant factors and their relative impacts on transit trip-making. To fill this void, this study employs multivariate regression and cluster analyses to examine the journey-to-work transit trip-making in Richmond. The following sections describe the research methodology, present and discuss findings of the analyses, and conclude with recommendations about transit service improvement.

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2. RESEARCH METHODOLOGY

This study intends to complement existing transit plans by conducting a rigorous statistical analysis on the socioeconomic/transit variables affecting Richmond's journey-to-work transit trip-making. Following the multivariate regression and cluster analyses, a professional judgment is exercised in interpreting those analytical results, from which conclusions and recommendations are drawn.

2.1. Data Sources

The principal data source is the year 2000 Census Transportation Planning Package (CTPP): Part I (At Place of Residence) and Part II (At Place of Work). Since most GRTC fixed-route bus transit services are provided within the City of Richmond and about 86% of the GRTC riders are Richmond residents according to the 2007 household survey conducted by GRTC (2008), only those transportation analysis zones (TAZs) within the City boundary are included for analysis. In addition to the CTPP data, selected transit-related socioeconomic data are also utilized in this analysis, including population density, automobile density, household density, and employment density.

2.2. Variable Definitions

In this study, the sole dependent variable is the percentage of workers taking bus transit. In CTPP, the term "worker" is used at both place-of-residence and place-of-work without distinction. In fact, the meaning of "worker" at place-of-residence is different from that at place-of-work. At place-of-residence, the term "worker" means the resident who is employed. Some workers work somewhere else during daytime, but sleep in the traffic analysis zone he/she stays at night. But at place-of-work, the term "worker" means the employee who works there during daytime.

Regarding the list of independent variables to be included, this study considers both internal (e.g., average fares, bus headways) and external factors (e.g., per capita income, automobile ownership) since both of them affect transit demand, even though no hard line separating internal from external factors exists (Taylor and Fink, 2002). According to the research conducted by the Mineta Transportation Institute (2002), the most significant factors influencing transit uses are external to transit systems. Of course, the relative importance of external and internal factors varies from place to place.

With respect to external factors, population and employment in a region can raise transit demand simply by expanding the potential ridership base (TranSystems et al., 2007). And the level of transit demand can be expected to vary between different demographic and socioeconomic subgroups of the population (Charles River Associates, 1997). It is generally believed that there exists a positive relationship between density and public transit ridership (Pushkarev and Zupan, 1977; Seskin and Cervero, 1996; Frank and Pivo, 1994).

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Therefore, population density (*popden*: persons/acre) and household density (*hhden*: households/acre) are included as independent variables of the production-side regression equation. On the other hand, retail employment density (*retempden*: employees/acre) and non-retail employment density (*nretempden*: employees/acre) are included as independent variables of the attraction-side regression equation.

Liu (1993) found that some external factors had a greater impact on demand for transit than internal factors. For this reason, several external variables are included in both production-side and attraction-side analysis, such as *parttime* (percentage of the part-time workers), *belowp* (percentage of the workers living in households below poverty status level), *zerov* (percentage of the workers living in households with zero vehicle), *onev* (percentage of the workers living in households with one vehicle). Auto density variable, *autoden* (automobiles/acre), is included as an independent variable of the production-side regression equation, with an understanding that automobile ownership and automobile availability will impact transit use at place-of-residence. In addition, this study also proposes other related variables: *dispct* (percentage of the disabled workers), *senior* (percentage of the workers who are 65 years and older), and *time* (percentage of workers traveling over short distance, i.e., less than 14 minutes).

TABLE 1 - DEFINITION OF VARIABLES

Variable Type	Variable Name	Variable Definition
Dependent Variable	*tranpct*	Percentage of the workers taking bus
Independent Variables for Both Production Side and Attraction Side	*parttime*	Percentage of the part-time workers
	dispct	Percentage of the disabled workers
	senior	Percentage of the senior workers (65 years and older)
	peak	Percentage of the workers making trips during a.m. and p.m. peak periods.
	time	Percentage of the workers whose travel times are less than 14 minutes
	belowp	Percentage of the workers whose households are below poverty status
	zerov	Percentage of the workers whose households have zero vehicles
	onev	Percentage of the workers whose households have one vehicles
	bstopwkr	Bus stop/worker
	bb_cover	Percentage of the TAZ that is transit-accessible (within ¼ mile radius)
Independent Variables for Production Side Only	*popden*	Population density: persons/acre
	autoden	Automobile density: automobiles/acre
	hhden	Household density: households/acre
Independent Variables for Attraction Side Only	*nretempden*	Non-retail employment density: employees/acre
	retempden	Retail employment density: employees/acre

As to the relative impact of internal factors, TranSystems (2003) expected "expand fixed route coverage" to have the largest relative impact among the service improvements. To describe bus route coverage and

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2067- 2462

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accessibility to bus stops, a variable *bstopwkr* (bus stops/worker) is assumed. In general, a bus stop's catchment area is determined based on a ¼-mile radius, or a 10-minute walking distance (Calthorpe, 1993; Cervero, 2004; Evans et al., 2007). Research shows that living and working near transit stations usually leads to higher ridership (Karash et al., 2008). Hence variable *bb_cover* is constructed to measure the percentage of each TAZ area which is transit-accessible, i.e., within a ¼-mile of a bus stop.

In the Richmond region, GRTC provides most transit services during peak periods. Therefore, transit percentage shares tend to be higher during peak periods than those during off-peak periods. In the 2000 census, journey-to-work trips only account for one-fifth of all urban trips, but two-fifths of transit trips, suggesting the importance of peak periods for transit trip-making (Pucher, 2004). The variable *peak* used in this study measures the percentage of the workers traveling during a.m. and p.m. peak periods.

Table 1 summarizes the list of variables used in this study. Other non-zonal variables, such as bus fare, auto operating cost, inter-zonal travel times, gasoline prices, etc., are excluded because they are typically used in a trip-interchange mode choice model (Meyer and Miller, 2001), rather than in a trip-end analysis as conducted in this study.

3. RICHMOND TRANSIT ANALYSIS

This study carries out the statistical analyses for Richmond's journey-to-work transit trip-making in two phases: a multivariate stepwise regression analysis followed by a cluster analysis. Out of the 216 TAZs in Richmond, only the ones with workers taking bus are included in the analyses. This leads to 137 valid TAZs in the production-side analysis and 143 valid TAZs in the attraction-side analysis. Figure 4 and Figure 5 show production-side and attraction-side transit uses by TAZs, respectively.

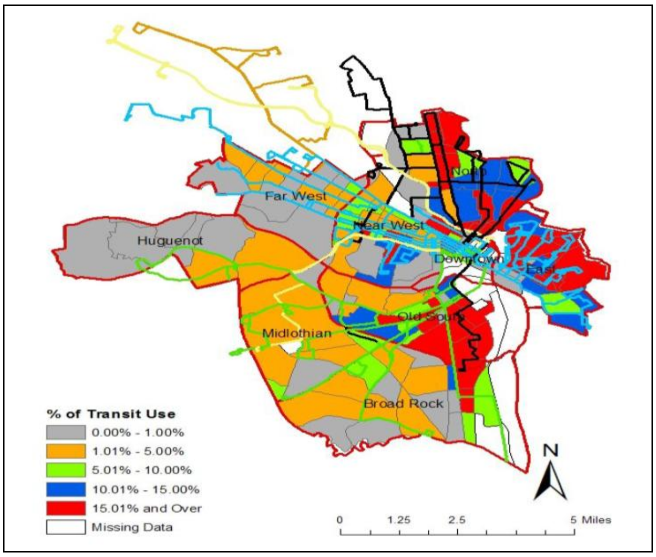

FIGURE 4 - PRODUCTION-SIDE TRANSIT USE BY TAZS

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2067- 2462

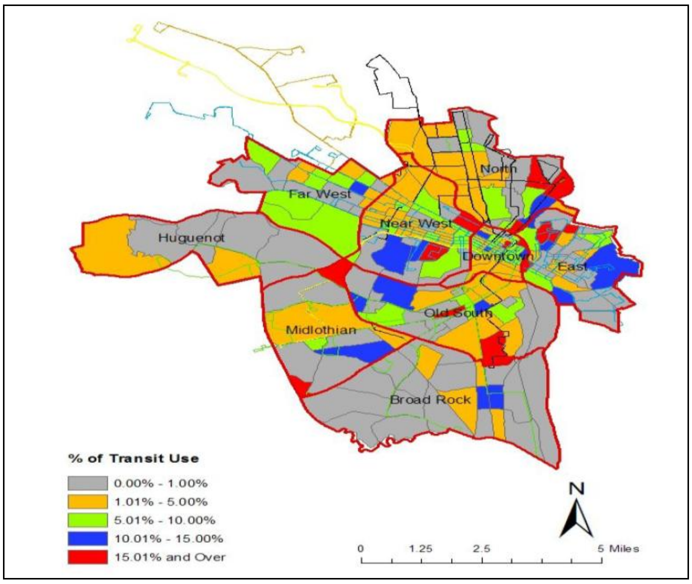

FIGURE 5 - ATTRACTION-SIDE TRANSIT USE BY TAZS

3.1. Statistical Results of Regression Analysis – Production Side

Tables 2 through 4 show correlation matrix and final model of stepwise regression results for the production-side transit use.

TABLE 2 - CORRELATION MATRIX (PRODUCTION SIDE, N = 137)

	tranpct	parttime	dispct	senior	peak	time	belowp	zerov	onev	bstopwkr	bb_cover	popden	autoden	hhden
tranpct	1.000													
parttime	.331**	1.000												
dispct	.104	-.134	1.000											
senior	-.095	.087	-.006	1.000										
peak	-.260**	-.314**	-.392**	.171*	1.000									
time	-.328**	.003	-.454**	-.072	.371**	1.000								
belowp	.539**	.566**	.212*	-.137	-.520**	-.252**	1.000							
zerov	.331**	-.013	.386**	.141	-.422**	-.310**	.511**	1.000						
onev	.350**	.123	.072	-.060	.011	-.172*	.314**	-.081	1.000					
bstopwkr	.692**	.168	-.137	.131	.083	-.278**	.133	.030	.253**	1.000				
bb_cover	.238**	.139	-.032	.059	-.084	.259**	.153	.222**	.125	.079	1.000			
popden	.013	.106	-.022	-.090	.021	.336**	.255**	.200*	.098	-.227**	.423**	1.000		
autoden	-.266**	-.013	-.271**	-.108	.266**	.471**	-.018	-.164	.077	-.234**	.315**	.782**	1.000	
hhden	-.108	.047	-.112	-.083	.119	.333**	.195*	.102	.170*	-.216*	.356**	.921**	.894**	1.000

**. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed).

TABLE 3 - REGRESSION MODEL SUMMARY AND ANALYSIS OF VARIANCE (PRODUCTION SIDE, N=137)
Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
6	.884[f]	.781	.771	.0732690

f. Predictors: (Constant), bstopwkr, belowp, bb_cover, autoden, popden, senior

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ANOVA[g]

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	2.495	6	.416	77.452	.00
Residual	.698	130	.005		
Total	3.193	136			

f. Predictors: (Constant), bstopwkr, belowp, bb_cover, autoden, popden, senior

g. Dependent Variable: tranpct

TABLE 4 - REGRESSION MODEL PARAMETER ESTIMATES (PRODUCTION SIDE, N = 137)

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
6	(Constant)	-.024	.028		-.866	.388
	pstopwkr	1.247	.087	.636	14.399	.000
	autoden	-.015	.002	-.453	-6.385	.000
	popden	.007	.002	.359	4.658	.000
	bleowp	.363	.055	.311	6.623	.000
	senior	-.423	.111	-.161	-3.794	.000
	bb_cover	.104	.034	.141	3.033	.003

a. Dependent Variable: tranpct

According to the above statistical analysis, the following factors significantly affected workers' decisions to take bus transit in year 2000 (sorted in a descending order of each independent variable's absolute value of beta weight, a standardized estimate measuring the variable's relative importance):

1. The most important factor is bus stops per worker (variable name: *bstopwkr*, beta weight: .636). This indicator measures bus transit accessibility, and serves as a proxy variable for walking distance to bus stop, number of bus routes and nearby bus stops, etc.;
2. Auto density (variable name: *autoden*, beta weight: -.453) is clearly a very important variable negatively impacting transit use;
3. Population density (variable name: *popden*, beta weight: .359) has a positive impact on transit use;
4. Another important variable affecting worker's transit use is the percentage of those workers whose households are below poverty level (variable name: *belowp*, beta weight: .311). This makes sense because captive transit riders do not have other choices but take transit;
5. Percentage of the senior workers (variable name: *senior*, beta weight: -.161) has a negative impact on transit use, which seems somewhat counterintuitive. This is perhaps due to its negative correlation with variables that are supposed to positively impact transit use (*time, belowp, onev, popden, autoden, and hhden*). There exist high-order interactions among these variables; and

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6. Percentage of a TAZ's transit-accessible area (variable name: *bb_cover*, beta weight: .141) is also positively related to transit use.

3.2. Statistical Results of Regression Analysis – Attraction Side

Tables 5 through 7 show correlation matrix and the final model of stepwise regression results for the attraction-side transit use. Overall, attraction-side regression equation yields a lower R-square (.497) than production-side one (.781). This is in line with the general pattern that trip attraction model is generally less accurate than trip production model. Therefore, trip attractions are balanced to trip productions for home-to-work trip purposes in the trip generation step of the conventional travel demand forecasting model.

TABLE 5 - CORRELATION MATRIX (ATTRACTION SIDE, N = 143)

	tranpct	parttime	dispct	senior	peak	time	belowp	zerov	onev	bstopwkr	bb_cover	nretempden	retempden
tranpct	1.000												
parttime	-.017	1.000											
dispct	.388**	-.126	1.000										
senior	.146	.205*	.020	1.000									
peak	.184*	-.033	.030	-.078	1.000								
time	.025	.327**	-.175*	.070	-.079	1.000							
belowp	.506**	.229**	.321**	.213*	-.009	.109	1.000						
zerov	.576**	.112	.302**	.199*	-.064	.131	.462**	1.000					
onev	.110	-.010	-.070	.140	-.047	.221**	.128	-.018	1.000				
bstopwkr	.395**	.014	.239**	.154	.011	-.013	.381**	.297**	.063	1.000			
bb_cover	.158	-.017	.094	-.111	.163	.019	.118	.081	.140	.057	1.000		
nretempden	-.087	-.163	-.167*	-.142	.325**	-.181*	-.167*	-.149	-.070	-.211*	.183*	1.000	
retempden	.060	-.034	-.136	-.085	.166*	.026	-.016	.036	-.012	-.212*	.233**	.496**	1.000

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

TABLE 6 - REGRESSION MODEL SUMMARY AND ANALYSIS OF VARIANCE (ATTRACTION SIDE, N = 143)

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
5	.705e	.497	.478	.0405728

e. Predictors: (Constant), zerov, belowp, peak, dispct, bstopwkr

ANOVAf

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	.222	5	.044	27.029	.000
Residual	.226	137	.002		
Total	.448	142			

e. Predictors: (Constant), zerov, belowp, peak, dispct, bstopwkr

f. Dependent Variable: tranpct

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TABLE 7 - REGRESSION MODEL PARAMETER ESTIMATES (ATTRACTION SIDE, N = 143)

Coefficients[a]

	Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
5	(Constant)	-.052	.017		-3.038	.003
	zerov	.419	.074	.396	5.634	.000
	belowp	.211	.071	.216	2.975	.003
	peak	.088	.026	.205	3.364	.001
	dispct	.100	.042	.156	2.373	.019
	bstopwkr	.190	.081	.156	2.337	.021

a. Dependent Variable: tranpct

The following five variables positively impacted workers' decisions to take bus transit in year 2000 at place-of-work:

1. Percentage of zero-vehicle workers (variable name: *zerov*, beta weight: .396);
2. Percentage of workers whose households are below poverty status level (variable name: *belowp*, beta weight: .216);
3. Percentage of workers traveling during peak periods (variable name: *peak*, beta weight: .205);
4. Percentage of disabled workers (variable name: *dispct*, beta weight: .156); and
5. Bus stops per worker (variable name: *bstopwkr*, beta weight: .156).

As shown in Table 8, the variables affecting production-side and the ones affecting attraction-side are very different.

TABLE 8 - SUMMARY OF IMPACTING VARIABLES

Category	Variable Name
Those variables affecting transit use at both place-of-residence and place-of-work	*bstopwkr*, *belowp*
Those variables affecting transit use at place-of-residence only	*senior*, *popden*, *autoden*, *bb_cover*
Those variables affecting transit use at place-of-work only	*dispct*, *peak*, *zerov*

3.3. Statistical Results of Cluster Analysis - Production Side

This study performs both production-side and attraction-side cluster analyses. Variables identified by the regression analysis of the production-side brought insights about workers' use of transit. In order to examine the potential of transit use by workers on the production side, the authors used the K-Means Cluster Analysis to classify Richmond TAZs into two clusters. The K-Means Cluster Analysis used *belowp*, *autoden*, *popden*, and *senior* variables from the regression results. It should be noted that the variables *bstopwkr* and *bb_cover* were excluded in the cluster analysis to avoid any potential bias since some TAZs do not have bus stops or the 1/4-mile buffer around bus stops in them.

According to the cluster center statistics (Table 9), Cluster 2 highlights the main characteristics of TAZs that might have a greater demand for transit use by workers. Compared to Cluster 1, Cluster 2 has a much lower auto density and a higher senior worker percentage, in spite of lower *popden* and *belowp* values.

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TABLE 9 - CLUSTER ANALYSIS (PRODUCTION SIDE, N = 137)

Final Cluster Centers

	Cluster	
	1	2
belowp	.1923	.1177
autoden	12.5569	3.6025
popden	23.8772	7.2525
senior	.0226	.0409

ANOVA

	Cluster		Error		F	Sig.
	Mean Square	df	Mean Square	df		
belowip	.097	1	.017	135	5.794	.017
autoden	1369.528	1	10.792	135	126.899	.000
popden	4720.649	1	21.750	135	217.046	.000
senior	.006	1	.003	135	1.687	.196

The K-Means Cluster Analysis also computed the distance from each TAZ to its cluster center. For Cluster 2, the distance measure can serve as an indicator of the potential of workers' use of transit in a TAZ, where shorter distances indicate higher potential while longer distances indicate that the TAZs are less homogeneous and farther away from the cluster center (Figure 6).

When mapped with the 1/4-mile buffer around bus stops (Figure 7), one can see the areas in Cluster 2 that have greater transit use potential but not yet served well by existing transit services. These areas are largely located in the urban fringe and outlying portions of the City.

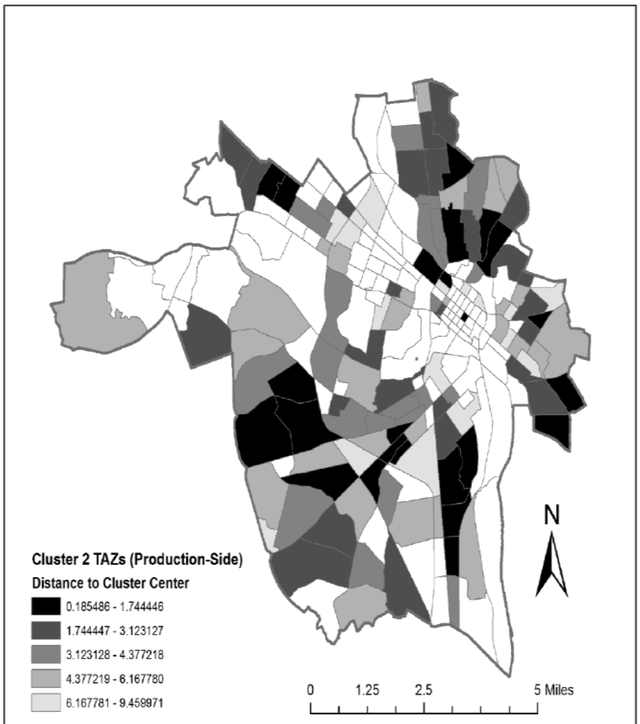

FIGURE 6 - CLUSTER 2 TAZS (PRODUCTION-SIDE) CLASSIFIED BY DISTANCE TO CLUSTER CENTER

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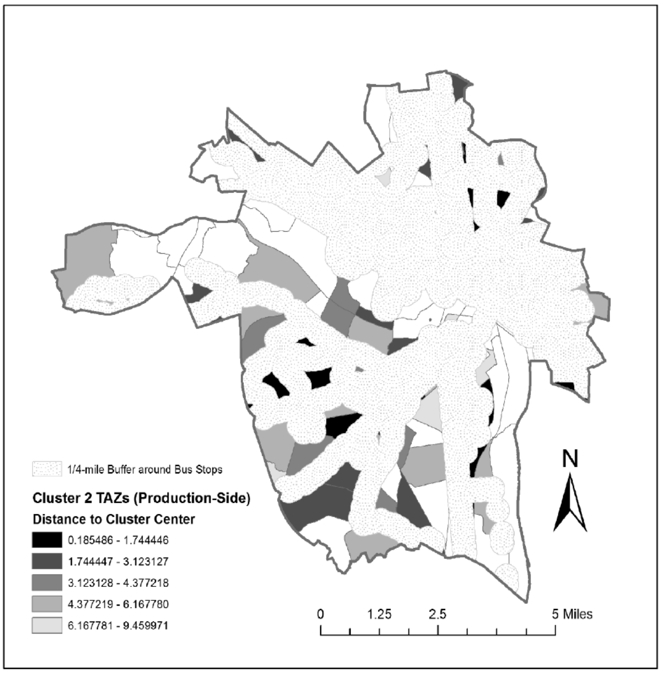

FIGURE 7 - CLUSTER 2 TAZS (PRODUCTION-SIDE) AND THE 1/4-MILE BUFFER AROUND BUS STOPS *STATISTICAL RESULTS OF CLUSTER ANALYSIS - ATTRACTION SIDE*

This study also conducted the K-Means Cluster Analysis for the attraction side, yielding the results shown in Table 10, Figure 8 and Figure 9. When compared to Cluster 2, Cluster 1 is obviously more transit-prone, due to its higher *zerov, belowp* and *peak* values, in spite of a slightly lower *dispct* value.

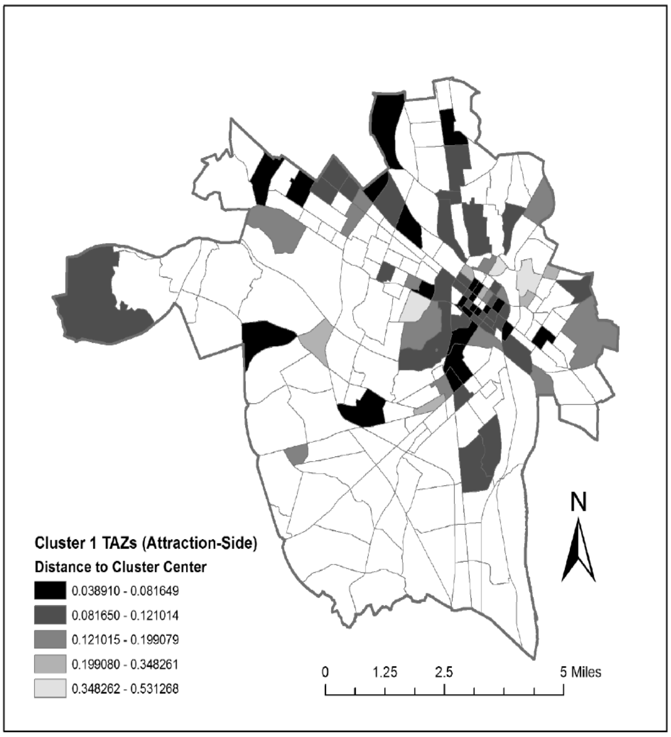

FIGURE 8 - CLUSTER 1 TAZS (ATTRACTION-SIDE) CLASSIFIED BY DISTANCE TO CLUSTER CENTER

TABLE 10 - CLUSTER ANALYSIS (ATTRACTION SIDE, N = 143)

Final Cluster Centers

	Cluster	
	1	2
zerov	.0775	.0709
belowp	.0688	.0621
peak	.6721	.4614
dispct	.1603	.1749

ANOVA

	Cluster		Error		F	Sig.
	Mean Square	df	Mean Square	df		
zerov	.002	1	.003	141	.534	.466
belowp	.002	1	.003	141	.484	.488
peak	1.575	1	.006	141	245.684	.000
dispct	.007	1	.008	141	.986	.332

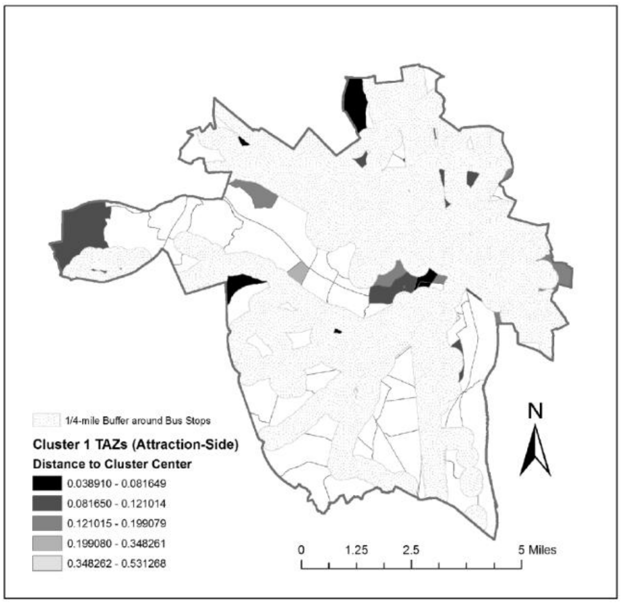

FIGURE 9 - CLUSTER 1 TAZS (ATTRACTION-SIDE) AND THE 1/4-MILE BUFFER AROUND BUS STOPS

Overall, attraction side has a high transit demand closer to downtown area. Except for some spotty areas, most of attraction-side transit demand is met. This situation is much better than production side.

4. CONCLUSIONS

Even though Richmond City only has a very small percentage of commuters using transit, a continuing provision and improvement of bus transit services is critical to this city due to the existence of higher percentage of minority, poverty-stricken residents with a high transit demand.

At present, downtown Richmond is well served by GRTC bus services. However, some outlying urban fringe areas (particularly South Side, Midlothian, Broad Rock, Huguenot Districts) are still underserved due to sparse transit network coverage and inaccessible bus stops.

The existing hub-and-spoke transit system is being challenged by the future suburbanization trend. Because of that, instead of exclusively investing on downtown-bound bus/rail transit routes, suburb-to-suburbs transit services should also be considered and strengthened by GRTC.

This study reveals that production side has higher unmet transit needs than attraction side. Therefore, local governments and transit planning agencies need to pay more attention to improving bus transit services in areas with greater potential of transit use.

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Management Research and Practice
Volume 2, Issue 3 / September 2010
eISSN
2067- 2462