Empirical Analysis of Relationship Between Accessibility and Economic Development

FINAL REPORT
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Submitted by

Dilruba Ozmen Ertekin, Ph.D

Dr. Joseph Berechman
Professor and Chairman*

Dr. Kaan Ozbay
Assistant Professor

Dept. of Civil & Environmental Engineering
Center for Advanced Infrastructure & Transportation
(CAIT)
Rutgers, The State University
Piscataway, NJ 08854-8014

*Tel Aviv University Israel

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16. Abstract

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TABLE OF CONTENTS

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INTRODUCTION

One of the key factors that play a pivotal role in a region's economic well-being is the presence of a reliable and efficient transportation infrastructure. This is mainly due to the fact that a well-developed transportation system provides adequate access to the region, which in turn is a necessary condition for the efficient operation of manufacturing, retail, labor and housing markets.

According to a recent report "Infrastructure and Economic Development-MetroPlan 2000" (BMAPC 1990), prepared by the Boston Metropolitan Area Planning Council, public infrastructure clearly influences land use and development patterns, zoning policies and the general economic environment. According to this report, when the Erie Canal opened, the cost of transporting wheat between New York and Buffalo fell from $100/ton to $10/ton, providing the Northeast with an early example of the benefits of accessibility improvements caused by transport infrastructure development. Presently, however, considering the highly developed transportation network in place, a major debate is occurring among economists, planners or public officials regarding the impact of further transportation infrastructure development on regional economic growth (Banister and Berechman 2000).

Figure 1 (Banister and Berechman 2000) depicts a general framework that describes the relationship between the transportation system and the economic growth. According to this framework, accessibility is improved as a result of investment in the existing transportation system. Improved accessibility, in turn, changes the travel and land use patterns and causes economic growth.
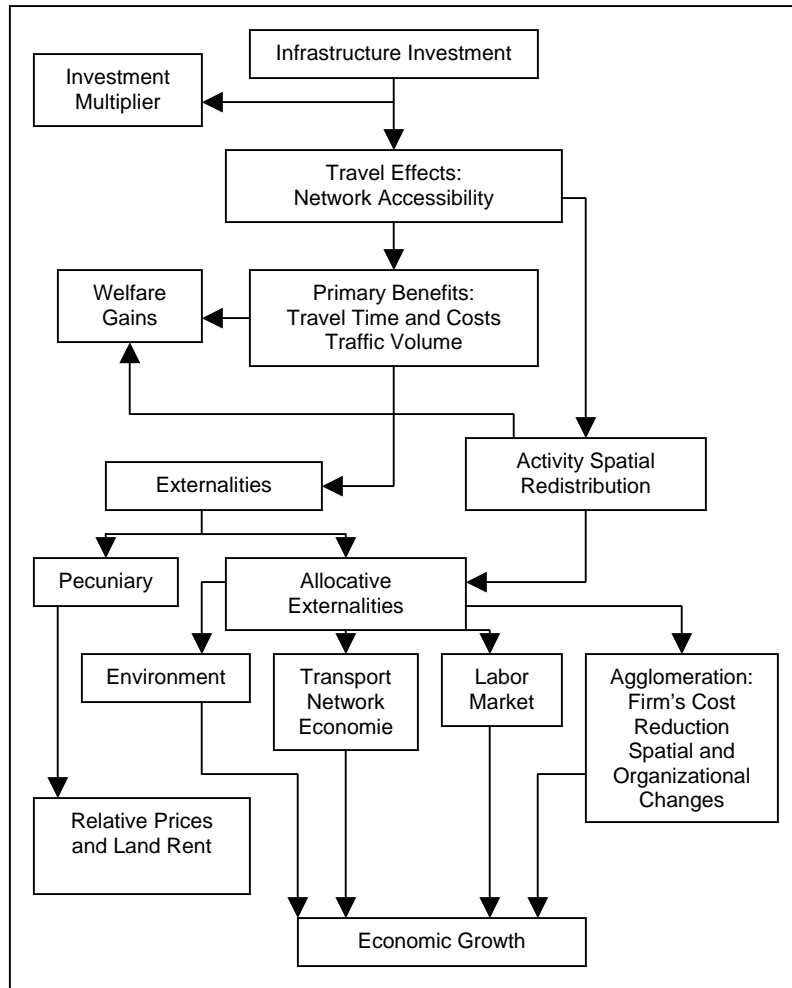
Figure 1. Framework Representing Relationship Between Accessibility and Economic Growth (Banister and Berechman 2000).

Given this view, this paper attempts to empirically substantiate the hypothesized relationship in Figure 1. This is done by first measuring the accessibility in the New York/New Jersey metropolitan area using several accessibility measures proposed in the literature. Subsequently we use multiple regression analysis to investigate the relationship between accessibility and economic development and evaluate the possible impacts of transportation investment on economic growth.

The structure of the paper is as follows. The next section presents the major motivations for the paper and then describes the methodology adopted to accomplish them. The succeeding section briefly reviews previous studies, followed by a section describing the study area and the database. Calculation of accessibility indexes and actual estimations as well as main results are presented in the next two sections, followed by a discussion of the results of the regression models. Policy analysis is presented next, followed by the key conclusions given in the last section.

ANALYTICAL APPROACH

The main goal of this paper is to study the existence and significance of the relationship between economic growth and transportation system performance. This relationship can be studied by using an analytical approach that correlates economic development with a variety of relevant factors, including an indicator of transportation system performance.

A good measure of economic development is longitudinal change in total earnings or income; another is employment growth. Transportation system performance, on the other hand, can be measured using a suitable accessibility index, which can be defined as "a combination of interzonal travel time and zonal activity levels" (DOT 1981).

The New York/New Jersey metropolitan area is chosen as the study area for this analysis. According to the Northern Jersey Transportation Planning Agency (NJTPA), northern New Jersey, which is at the heart of the state's economic activity, is served by a vast multimodal transportation system that supports nearly every aspect of economic activity in the region. This transportation system represents more than a century of public and private investment. New York City, on the other hand, is a major financial and commercial center that creates jobs and wealth for the whole region. Efficient and reliable transportation between New York City and the rest of the region is seen as a key to ensuring the continuation of economic activity in this region. The data collected for the study region are used to perform multiple linear regression analysis to investigate the hypothesized relationship between economic development measures and accessibility. Thus in the next section we first review a number of accessibility indexes proposed in the literature and their relationship to economic growth.

REVIEW OF STUDIES ON IMPACT OF TRANSPORTATION INVESTMENT ON ECONOMIC GROWTH

A review of the literature on the relationship between infrastructure investments and economic growth shows that, by and large, studies have reached similar conclusions, although they differ in the specific questions asked, the methodological approaches used and the types of data employed. A literature review reveals a relationship between accessibility (transportation) and economic development in the regions studied, which is one thing most of the previous studies agreed upon. In fact, the results of the regression analysis in our paper contributed to the findings of the majority of the similar studies that there is a strong relationship between economic development and transportation investments. Some examples of previous studies are summarized below.

Aschauer (1991) has analyzed the relationships between transportation infrastructure spending and economic growth and labor productivity using a production function-based growth model. The study used annual change in output per employee as the dependent variable. The database was composed of observations on highway and transit spending in the 48 continental US States, between 1969 and 1986. The study's principal finding is

that the effect of total transportation expenditures on the growth rate of the ratio of private capital to labor is high (R^2=0.44) (Banister and Berechman 2000).

Forkenbrock and Foster (1990) have studied the economic benefits of a corridor highway investment. They first developed a conceptual framework and then applied it to evaluate four alternative routes in an 805 km (500 m) corridor connecting two large metropolitan areas in the Midwest region of the United States. An Input-Output model was used in their study, which concluded that highway investments promote local economic development by lowering transportation costs relative to other locations. Boarnet (1996) has examined the way highway investments redistribute economic activity by dividing the economic impacts of transportation infrastructure into a direct and an indirect effect. The direct effect is considered to be the impact on locations near streets or highways, and the indirect effect is any impact that occurs at locations more distant from the highway corridor. A loglinear Cobb-Douglas specification was applied to California data such as county employment, using capital stock in the county and other counties as independent variables, and the county's output as dependent variable. It was concluded that the direct and indirect effects of investing in transportation infrastructure were of equal and opposing magnitude.

Clay et al. (1988) examined some counties in North Carolina and focused on changes in employment and highway expenditures. They concluded that highway investment is central to economic development, based on the fact that large spending on highways has been accompanied by rapid employment growth in North Carolina's metropolitan areas.

Isserman et al. (1989) used a quasi-experimental approach to investigate the effect of highways on smaller communities and rural areas. They examined income growth rates during the period of 1969-1984 for 231 small rural cities, some with highway access, some without. It was found that the cities located near highways had faster economic growth.

Although all the above studies identified some kind of positive relationship between highway investment and local economic development, several studies indicated little or no effect of transportation investment on local economic growth. The major claim of these studies is that the economic growth that would have occurred anyway is located near highways, but local economic growth is not created and stimulated by transportation investment.

Stephanedes and Eagle (1986) used a time-series approach to investigate the relationship between state highway expenditures and changes in employment levels in 30 nonmetropolitan Minnesota counties between 1964 and 1982. Grouping all 87 Minnesota counties, they found no overall relationship between highway expenditures and changes in employment levels. For a subgroup of regional centers, however, highway expenditures did appear to engender job growth.

Review of Accessibility Indexes

In this section we survey some accessibility measures commonly used in the literature to assess the performance of the transportation system. A popular accessibility measure is Hansen's Accessibility Index (Hansen 1959), which is shown in expression 1.

$$A_i = \frac{\sum_{j=1}^{n} W_j . e^{-\beta . c_{ij}}}{\sum_{j=1}^{n} W_j} \tag{1}$$

where, A_i= accessibility of zone i to opportunities in zone j for j=1,......,n
W_j= measure of attractiveness of zone j
c_{ij}= cost of travel from zone i to zone j (represented by travel time, distance, and so on)

Measures of attractiveness can be zonal total employment, retail employment, household characteristics (such as income), or population. Ingram (1971) proposed a measure, sometimes called integral accessibility, shown in expression 2.

$$A_i = \sum_{j=1}^{N} d_{ij} \tag{2}$$

where, A_i=integral accessibility at i^{th} point
d_{ij}=relative accessibility of point j with respect to point i (minutes)

Based on (2), a new accessibility index can be developed for a given region by integrating the integral accessibility index over all the points (zones) within the area. This gives a normalized index, which can be formulated as follows (Allen et al. 1993):

$$A_i^{'} = \frac{1}{N-1} \sum_{j=1}^{N} d_{ij} \tag{3}$$

where, N_i=Number of zones (18 in this case)

If we interpret d_{ij} as the travel time between locations i and j, then $A_i^{'}$ represents the average travel time between a given location i and all other locations in the study area. In location theory, the node with the lowest $A_i^{'}$ is called the median point of the network (Allen et al. 1993). Since the index given in (3) measures the cost of travel between locations in terms of time (or distance), a high value of $A_i^{'}$ represents a low level of accessibility.

Black and Conroy (1977) suggested an accessibility index, which is the area under the curve of the cumulative distribution of opportunities reached within a specified travel time. The numerical measure calculated is the area bounded by the curve of the distribution, the travel time axis, and a selected travel time ordinate. This accessibility index is shown in expression 4.

$$K_i = \int_0^T A(t)dt \tag{4}$$

where, **A(t)**=cumulative proportion of activities of region reached within given time limit
  t=travel time (minutes)
  T=chosen travel time ordinate

The variable K_i contains information about the proportion of opportunities reached and about the distribution of these opportunities over time. In (4), accessibility is high when many opportunities can be reached within a travel time T; therefore a large value of K_i indicates a good level of accessibility.

A variation of the accessibility measure given in expression 2 is shown in expression 5.

$$A_i = \sum_{i=1}^{k} c_{ij}^{\beta} \qquad \forall j = 1,......,k \tag{5}$$

$$i \neq j$$

where, **c_{ij}**=relative distance or travel time of point j with respect to point i. (travel time in
  minutes)
  β= exponent (assumed to be –2 as a default value)

The value of the parameter β reflects the specific characteristics of the transportation system such as comfort level, safety, and so on, that cannot be directly measured by travel time and / or distance between zones. Its value needs to be calibrated using real-world data. A common value used for β in the literature is –2. This default value establishes an inverse relationship between the square of travel time and accessibility; hence the value of this index increases as accessibility improves.

Accessibility and Economic Growth

Given the above accessibility measures, the next question is how to link accessibility improvements with regional economic growth. Dalvi and Martin (1976) examined relative accessibility in the London region. The accessibility measure used is a Hansen-type index with four measures of areal attractiveness; total employment, employment per area, number of households and size of population in an area. With total employment as the attractor variable, the central business district was found to be most accessible relative to the rest of inner London. However, when households or population were used as measures of attractiveness the opposite result was obtained; with employment as the attractor variable, accessibility differentials between areas appeared less pronounced than with households or population.

Allen et al. (1993) proposed an accessibility index that captures the overall transportation access level of Philadelphia and other largest U.S. metropolitan areas.

Using this index, a regression analysis was performed for data from the 60 largest U.S. metropolitan areas in order to investigate the impact of accessibility on the employment growth rate. The results showed that accessibility has a considerable impact on a region's economic growth.

Cervero et al. (1995), traced changes in job-accessibility indexes for the San Francisco Bay Area between 1980 and 1990. These indexes were computed for 100 residential areas and the region's 22 largest employment centers and were further refined based on occupational match indicators between residents' employment characteristics and labor occupational characteristics at workplaces. A gravitylike measure of job accessibility was used in this analysis, which discovered that peripheral areas were the least job accessible, whereas employment centers were generally the most accessible when occupational matching was accounted for.

From this brief review, we can see that simple accessibility measures can have a significant explanatory power relative to changes in regional employment, income and other measures of regional economic growth.

DESCRIPTION OF STUDY AREA AND DATA

The study area includes the northern New Jersey and southern New York areas, specifically the following counties: Sussex, Passaic, Bergen, Essex, Hudson, Hunterdon, Ocean, Warren, Monmouth, Morris, Somerset, Middlesex and Union counties in New Jersey; and Bronx, Kings, Queens, and Richmond counties and New York City in New York. Figure 2 depicts the study area.
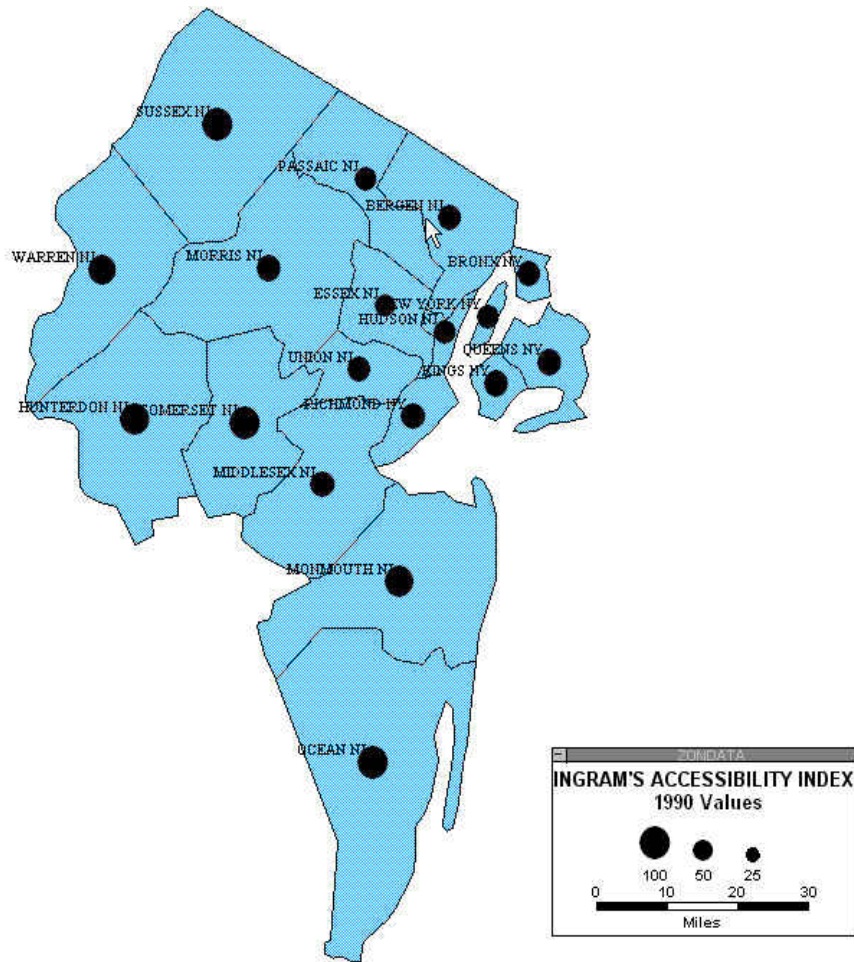
Figure 2. New York-New Jersey Metropolitan Area Accessibility Measured By Ingram's Method (Expression 3).

(circles indicate each county's accessibility index; smaller circles indicate more favorable index)

The major source of data for this study is the Complete Economic and Demographic Data Source (CEDDS) by Woods and Poole Economics, Inc (Woods, 2000). Annual total employment, population, total earnings, and total retail sales figures for the years 1990 and 2000 constitute the database used in this study. All monetary values were adjusted for inflation.

Travel times between each pair of counties in the study area were obtained from the North Jersey Transportation Authority and were calculated using the calibrated Tranplan model to generate highway congested speeds with travel impedances (low occupancy and high occupancy) for 1990 and 2000. In this study, 1990 and 2000 travel times based on congested speeds were considered for calculating the respective accessibility indexes.

ANALYTICAL FRAMEWORK FOR MODELING RELATIONSHIP BETWEEN ECONOMIC GROWTH AND ACCESSIBILITY

In this study, we test the hypothesis that a relationship exists between economic growth and accessibility. Our approach is similar to the one presented by Linneman and Summers (1991), although more limited in scope. While they attempt to study the patterns of urban population decentralization as well as population and employment growth in 60 metropolitan areas, our study focuses specifically on the New York-New Jersey metropolitan area and the economic growth in individual New Jersey and New York counties.

Within the limited scope of this study, we conjecture that economic growth in each county in the study area can be measured using the average annual employment growth value or average annual total earnings growth value between the years 1990 and 2000. However, we assume in our model that each county interacts, at least with neighboring counties, in terms of economic activities. This assumption is consistent with the recent findings of Boarnet (1996), where the interaction among an individual county and neighboring counties has been studied in the context of the impact of highway capital in one county. Boarnet (1996) concluded that there is "sufficient evidence of indirect economic effects of highway capital stock in one county across neighboring counties".

Thus we use two explanatory variables that represent this relationship; average annual employment growth value and average annual population percent change in adjacent counties. Furthermore, we use base year population and employment for each county as other explanatory variables in our regression model. These variables are commonly used in "land use models" to represent "the potential of growth" in a given area. Putnam (1983, p. 163) argues, "The past and / or present location of employment exerts a significant influence on the future location of employment." Furthermore, he states that the location of the current resident population has a significant influence on the location or future location of all types of employment. An additional economic indicator, growth value of average annual total earnings, has also been tested in the models where average annual employment growth value is used as the dependent variable.

Finally, we introduced an accessibility term to represent the impact of transportation system performance. We have tested four different accessibility measures discussed in the previous section, but the simple accessibility index given in expression 5, which is simply based on the inverse of the travel time, appears to produce the best results for the hypothesized regression analysis framework. We believe this accessibility measure, which is similar to the distance function used by the gravity models, can be seen as the relative impedance of a county i with respect to other counties in the study area.

Other similar studies used even simpler measures such as the "centerline miles of certain type of roadways in each analysis zone" (Reilly 1997) to incorporate the effects of travel cost. However, Putnam (1983) argues that the location of employment in a

particular zone is directly proportional to the "accessibility of this area with respect to other zones". Now, the way this accessibility measure is calculated in the context of an employment prediction model needs further attention. Aside from the accessibility indexes discussed in this paper, at least one more "impedance function" can be used as an alternative to the exponential type of function, $c_{ij}^{-\beta}$ proposed in expression 5. Wilson (1969) proposed an impedance function of the form $e^{-\beta c_{ij}}$, where β is an empirically determined constant. Both these functions are a special form of modified gamma function or so-called "Tanner Function" (Cripps and Foot 1969) shown in the following expression:

$$f(c_{ij}) = c_{ij}^{\alpha} e^{\beta c_{ij}} \qquad (6)$$

where it is usually assumed that β<0 for all relevant cases. The Tanner function is also used in several well-known employment models such as EMPAL (Putnam 1983). The Tanner function has the desirable property that, when β<0, it has the same shape as $c_{ij}^{-\beta}$. We show this property in Figure 3 for β=-2, where similar behavior for both travel time expressions is shown. Due to this property, the use of $c_{ij}^{-\beta}$ instead of the more widely used index shown in expression 6 as the accessibility measure did not affect our results. Putnam (1983) also states that the value of β in expression 6 will range between 0.00 and -2.00, but some calibration results for the employment location models he presented produced much higher β values of up to –9 as a result of the best-fit calibration of the modified gamma function shown in expression 6.

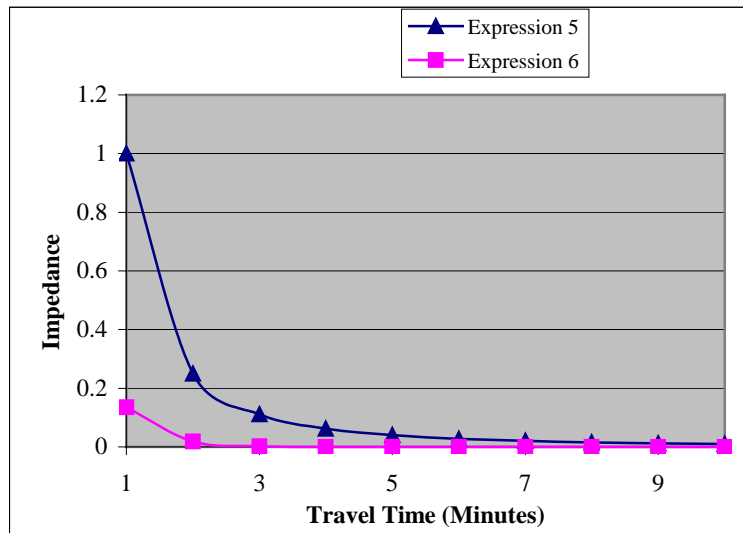**Figure 3. Comparison of Two Different Impedance Functions.**

For $c_{ij}^{-\beta}$, used in this paper, we have tested different β values that range between negative1.5 and negative 2.5 by using the values of the accessibility index obtained for different β values. We have observed that the change in β values beyond -2 did not make statistically significant changes that improved our results.

MODEL SPECIFICATION

Two different sets of linear regression models were developed using employment growth and total earnings growth as the dependent variables. The independent variables include each county's total population and total employment per acre, employment and population growths in adjacent counties, and total retail sales growth and three accessibility indexes (Expressions 3-5).

The accessibility indexes used in this study were relative accessibility indexes, that is, the accessibility index of a county relative to all other counties. Using expressions 3-5 and an 18x18 travel time matrix, an accessibility index for each of the 18 counties in the study area was calculated. The results are shown in Table 1.

Table 1. Estimated Values of Accessibility Indexes for the Years 1990 and 2000

Location	Accessibility Index					
	Expression3[a],(In minutes)		Expression 4[b]		Expression 5[b]	
	1990	2000	1990	2000	1990	2000
Bergen (NJ)	59.76	56.77	1914	2178	0.08	0.096
Bronx (NY)	61.93	55.81	2813	2967	0.171	0.229
Essex (NJ)	53.44	49.68	2135	2432	0.42	0.203
Hudson (NJ)	55.8	50.45	2863	3014	0.136	0.394
Hunterdon (NJ)	91.06	87.05	-802.2	-107.1	0.024	0.017
Kings (NY)	64.02	59.09	2529	2710	0.105	0.164
Middlesex (NJ)	69.31	63.79	68.34	636.42	0.035	0.062
Monmouth (NJ)	87.16	85.58	46.26	151.02	0.077	0.091
Morris (NJ)	65.7	61.05	936.342	1032	0.04	0.042
New York City (NY)	57.58	51.7	3482	3616	0.067	0.126
Ocean (NJ)	103.29	104.02	-630.36	-124.326	0.164	0.056
Passaic (NJ)	54.28	50.71	2139	1913	0.705	0.537
Queens (NY)	65.56	60.6	2494	2660	0.163	0.257
Richmond (NY)	68.45	62.28	1377	2010	0.214	0.599
Somerset (NJ)	116.23	80.28	-47.94	439.788	0.006	0.013
Sussex (NJ)	122.23	115.49	-531.69	-420.66	0.018	0.013
Union (NJ)	59.33	52.81	953.64	1668	0.026	0.033
Warren (NJ)	83.67	78.78	107.718	-1320	0.154	0.209

[a]Smaller values are favorable.

[b]Larger values are favorable.

To estimate the accessibility index given by expression 4, which measures accessibility to employment, 1990 and 2000 employment figures were used. In this study, a 60 min travel time ordinate has been tested. Thus, the accessibility indexes represent the number of jobs reached within a 60 min travel time from each county to all other counties. A sample calculation for New York City is given in expression 7 below. The cumulative distribution plot of New York City given in Figure 4, is expressed in terms of a third-degree equation and then integrated to find the accessibility index.

$$\int_0^{60} -0.0001 \cdot x^3 + 0.0134 x^2 + 0.6804 x + 26.947 \, dx = 3.482 \cdot 10^3 \quad \blacksquare \tag{7}$$

New York, NY

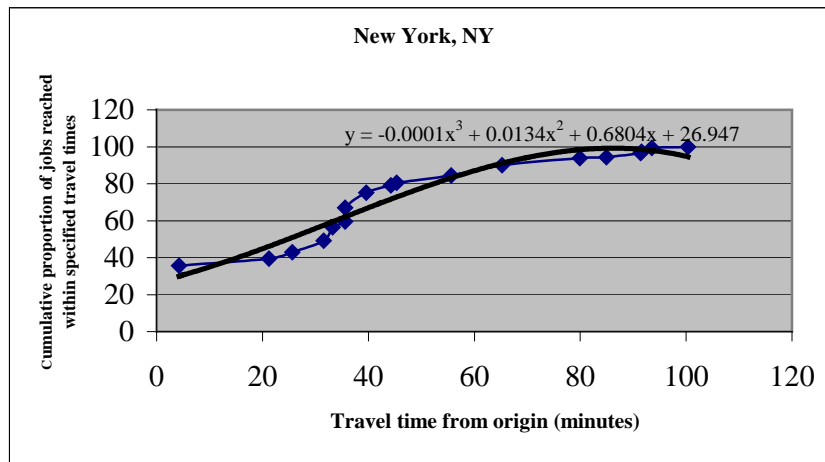$$y = -0.0001x^3 + 0.0134x^2 + 0.6804x + 26.947$$

Figure 4. Cumulative Distribution Of Jobs Reached Within specified Travel Times (1990 Employment Figures).

The value calculated using expression 7 indicates the total number of jobs reached within a 60 min travel time from New York City to all other locations (in a 360^0 circle with radius equal to a 60 min travel time distance, with New York City being the origin) in the study area.

As seen in Table 1, counties located closer to New York City, which holds 35% of all the employment in the study area, have relatively higher accessibility when measured by the accessibility index given in expression 4. Still, the level of economic activity in each location is also an important factor to maintain a high accessibility index. For example, Passaic, which is farther away from New York City, has much higher accessibility index than Richmond, which is closer to New York City. The reason is that Passaic holds approximately 3% of the total employment in the study area, whereas Richmond holds only 1 % of total employment.

A thematic map representation of accessibility index using expression 3 (Ingram's accessibility index) from Table 1 is given in Figure 2. It shows the accessibility patterns in the study area based on 1990 travel times. The interesting point to notice is that counties such as Middlesex, Union and Essex have greater accessibility than counties

in the southern or northwest part of the study area. This can be explained in terms of the nature of this accessibility index; since it measures travel time from a point to all other points, the central points tend to have higher accessibility than the outer points. The northeastern New Jersey counties and New York counties experience good accessibility that is also due to the good highway network connecting these counties.

The following hypotheses are to be tested in this study:

> H_0: No relationship exists between economic growth and accessibility
> H_1: A significant relationship exists between economic growth and accessibility.

A t-test will be used to test the hypotheses and if the t-values of the variables are found to be greater than the critical t-value (which is considered as 2.0 in this study), the null hypothesis will be rejected.

The hypotheses mentioned above are based on the following assumptions:
o   Economic growth in each county in the study area can be measured using average annual employment growth value or average annual total earnings growth value between the years 1990 and 2000; and
o   Each county interacts, at least with neighboring counties, in terms of economic activities.

The general form of the multiple linear regression model developed in this study is shown in expression 8, which represents the economic growth in each county in the study area.

$$AAEGR(or\ AATEC) = \beta_0 + \beta_{TBP}.TBP + \beta_{TBE}.TBE + \beta_{AAEGRadj}.AAEGR_{adj} + \beta_{AAPCadj}.AAPC_{adj} \quad (8)$$
$$+ \beta_{AARSC}.AARSC(or\ \beta_{AAEGR}.AAEGR) + \beta_{AI}.AI$$

where,

AAEGR: Average Annual Employment Growth Value between years 1990-2000
AATEC: Average Annual Total Earnings Change between 1990-2000
TBP: Total Base year Population Per Acre in 1990
TBE: Total Base year Employment Per Acre in 1990
AAEGR_adj: Average Annual Employment Growth Value in adjacent counties (except the county itself) between years 1990-2000
AAPC_adj: Average Annual Population Change in adjacent counties (except the county itself) between years 1990-2000
AARSC: Average Annual total Retail Sales Change between years1990-2000
AI: Differences of accessibility index values measured by three different methods between 1990- 2000 (that is, change in accessibility index between 1990-2000 for each county).

All the variables can take any real value within the minus infinity to plus infinity range. None of the variables used in our models are limited range variables.
Six regression models have been developed for expression 8 with 2 different dependent variables (AAEGR and AATEC) and with the 3 different AI terms. Expression 9 is an

example of the calculation of the variable AI used in regression models according to Ingram's accessibility index:

AI_i=(Ingram's Acc. Index in year 2000 for county i)-(Ingram's Acc. Index in year 1990 for county i)　　　(9)

The parameters of the regression equations have been estimated using simple OLS approach. Since the dependent and independent variables used in this analysis are not limited- range variables (that is, not between 0 and 1, or not between 0% and 100%), there was no need to use Generalized Least Squares (GLS) technique by transforming those variables with appropriate link functions (such as logit transformation).

Table 2 summarizes different variations of two sets of regression models in terms of variables used by each model. After running a regression for all the models shown in Table 2, models 2 and 4 turned out to be theoretically sensible models and will be discussed in detail.

Table 2. Variables Used in Regression Models

Variables	Regression Models on Annual Employment Growth			Regression Models on Annual Total Earnings Growth		
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Dependent Variables:						
Average Annual Employment Growth	+	+	+			
Average Annual Total Earnings Change				+	+	+
Independent Variables:						
Total Base year Population	+	+	+	+	+	+
Total Base year Employment	+	+	+	+	+	+
Average Annual Employment Growth in Adjacent Counties	+	+	+	+	+	+
Average Annual Population Change in adjacent Counties	+	+	+	+	+	+
Average Annual Retail Sales Change	+	+	+			
Average Annual Employment Growth				+	+	+
Accessibility Index difference by Expression.3	+			+		
Accessibility Index difference by Expression 5		+			+	
Accessibility Index difference by Expression 4			+			+

For models 2 and 4, the explanatory power of the regression equation based on the statistical measures appears to be very good. Moreover, p-value tests with the level of significance $\alpha = 0.05$, for the estimated parameters of independent variables show that all the estimated parameters, except two variables in model 4, are statistically significant. The signs of independent variables shown in Table 2 are consistent with the expected signs for each variable. Based on these test results shown in Table 3, we can thus conclude that a good relationship exists between accessibility and economic growth as measured in the model.

In order to validate the robustness of the regression results and the appropriateness of the OLS application, several statistical tests were performed as explained in the following paragraphs.

The correlation and multicollinearity among the variables have been tested. The correlation between model errors at different time periods is called autocorrelation. Notice that the data set used in this paper is not time-series data; therefore, there is no reason to suspect existence of autocorrelation. Multicollinearity is present in the database only if two or more regressors are highly correlated. This correlation is presented in Table 4, in which correlation between AARSC and AI (accessibility index difference measured by expression 5) is very low compared to correlation between AARSC and other accessibility indexes.

To check the existence of heteroscedasticity[1], White Test[2] was performed. The test results show that there is no heteroscedasticity in the data, since the product of the number of observations and the R^2 value from the White Test of model 2 is 17.1 which is less than the critical value of the chi-square variable for $\nu=14$ and $\alpha=0.05$, ν being the degrees of freedom (The critical value from the statistical table is 23.68). Test results for model 4 also show no sign of heteroscedasticity. Therefore, it can be concluded that both models are robust and statistically meaningful.

However, as can be seen from Table 3, two of the independent variables of model 4 have relatively low t-values (less than 1) thus implying statistically insignificant parameter values. Nonetheless, due to the economic significance of these values, we decided to keep them in our model. On the other hand, due to the higher statistical significance of independent variables in model 2 and the virtually very similar nature of both models in terms of dependent and independent variables used, we decided to focus on model 2 to further analyze the relationship between accessibility change and economic growth.

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[1] Heteroscedasticity is the problem encountered in regression analysis when the variance of the error term in a regression is not constant for every observation.

[2] The White Test involves regressing the squared residuals on all the independent variables, their squared values, and their cross products. If the product of the number of observations and R^2 exceeds the critical value of the chi-square variable with the number of degrees of freedom given by the number of independent variables (at the chosen significance level), the null hypothesis of no heteroscedasticity is rejected (York 2001).

Table 3. Regression Results: Parameters for Model 2 and 4

Variables	Model 2	ES[c]	Model 4	ES
Intercept	-19.64 {0.001}[a], (-4.24)[b]		9.8 {0.024}, (2.628)	
TBP	0.212 {0.074}. (1.97)	+	-0.154 {0.205}. (-1.348)	-
TBE	-0.108 {0.129}. (-1.64)	-	0.165 {0.04}. (2.329)	+
AAEGR$_{adi}$	-1.43 {0.075}. (-1.97)	-	-0.562 {0.54}. (-0.631)	-
AAPC$_{adi}$	2.53 {0.05}. (2.18)	+	0.8 {0.587}. (0.56)	+
AARSC	1.26 {0}. (5.68)	+		
AAEGR			1.034 {0}, (5.24)	+
AI	11.68 {0.248}. (1.22)	+	-0.529 {0.03}. (-2.485)	-
Multiple R^2	0.94		0.95	
R^2	0.88		0.91	
Adjusted R^2	0.81		0.86	
Standard Error	4.51		5.48	
Skewness of Residuals	-0.517		0.023	
Kurtosis of Residuals	-0.118		0.005	
Observations	18		18	

[a]Numbers in braces are the p-values, or the probabilities that the independent variable has no effect on the dependent variable. Smaller p-values are favorable.
[b]Numbers in paranthesis are the t-statistics values.
[c]Expected sign of the independent variable.

Table 4. Correlation Table

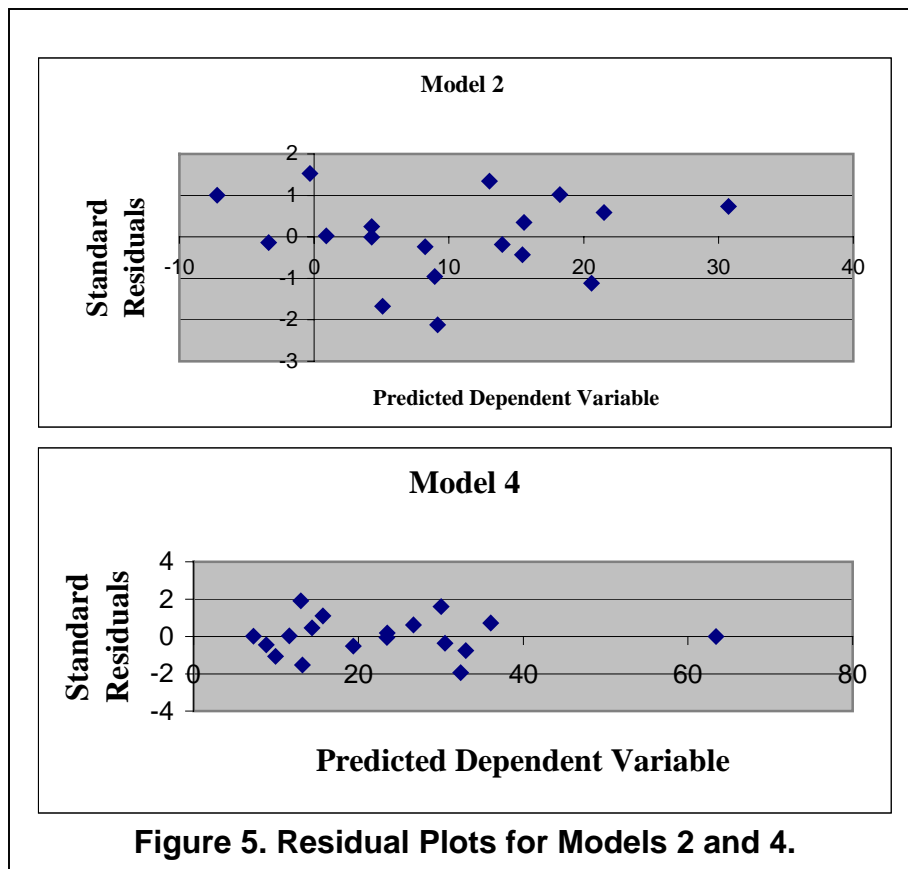|	AAEGR	AATEC	TBP	TBE	AAEGR$_{adj}$	AAPC$_{adj}$	AARSC	AI[a]	AI[b]	AI[c]
AAEGR	1									
AATEC	0.892	1								
TBP	-0.396	-0.270	1							
TBE	-0.274	-0.050	0.805	1						
AAEGR$_{adj}$	0.437	0.361	-0.419	-0.182	1					
AAPC$_{adj}$	0.541	0.435	-0.535	-0.318	0.955	1				
AARSC	0.863	0.893	-0.467	-0.152	0.522	0.565	1			
AI[a]	-0.494	-0.653	0.065	0.024	-0.065	-0.069	-0.499	1		
AI[b]	0.114	0.151	0.197	0.078	-0.243	-0.320	0.026	-0.072	1	
AI[c]	0.262	0.286	-0.007	-0.025	-0.159	-0.136	0.162	-0.141	0.076	1

[a] Difference in accessibility index measured by Ingram's method as given in expression 3 between 1990-2000.
[b] Difference in accessibility index measured by the formula given in expression 5 between 1990-2000.
[c] Difference in accessibility index measured by Black and Conroy's graphical method as given in expression 4 between 1990-2000.

We have also tested the distributions of the estimation errors to analyze the patterns of estimation deviations. Errors, represented by the residuals, should be normally distributed for each set of values of the independents. Due to the central limit theorem, which assumes that even when error is not normally distributed, when the sample size is large, the sampling distribution will still be normal, violations of normality assumption usually have little or no impact on substantive conclusions for large samples. However, when the sample size is small, tests of normality are important and a simple normality test using skewness and kurtosis coefficients can be conducted Kurtosis is a measure of how outlier prone a distribution is. The kurtosis of the normal distribution is 3. Distributions that are more outlier prone than the normal distribution have kurtosis greater than 3; distributions that are less outlier prone have kurtosis less than 3. The normality of a distribution is, on the other hand, characterized by a skewness coefficient equal to 0.

As seen in the last rows of Table 3,both models developed in this study passed the normality test since the skewness and kurtosis coefficients are found to be less than 0 and 3, respectively. Finally, "homoscedasticity" of the errors was checked to determine if the residuals are dispersed randomly throughout the range of the estimated dependent variable. According to the homoscedasticity assumption, variance of residual error should be constant for all values of the independent(s), and if the homoscedasticity assumption is violated, conventionally computed confidence intervals and conventional t-tests for OLS estimators can no longer be justified. The nonconstant error variance can be observed by just plotting standardized residuals against estimated values of the dependent. A homoscedastic model will display a cloud of dots, whereas lack of homoscedasticity will be characterized by a pattern such as a funnel shape, indicating greater error as the dependent variable increases. The plots of residuals against the predicted values of the dependent variable for models 2 and 4 depicted in Figure 5 show that the desirable statistical property of homoscedasticity exists for the residuals of both models.

Model 2

Standard Residuals vs Predicted Dependent Variable

Model 4

Standard Residuals vs Predicted Dependent Variable

Figure 5. Residual Plots for Models 2 and 4.

RESULTS AND DISCUSSION

The main contribution of the macroeconomically based models presented in the previous section is the ability to demonstrate the importance of public infrastructure in promoting economic growth and private capital productivity. Models 2 and 4 developed in this study, employ two conventional economic growth indicators: changes in average employment growth, and change in average annual total earnings. Two of the eight independent variables-population and employment in each county- are taken in terms of population and employment per acre to reflect the difference in population and employment densities in each county in the study area.

This kind of representation of population and employment avoids bias towards geographically large counties and is also an economically important consideration, since the level of economic activity tends to increase with increasing population and employment densities as well as average income levels. Thus our models incorporate the effect of population and employment density. In addition to the population- and employment-related variables, model 2 has an extra variable: annual retail sales. However, in order to avoid having two highly correlated variables; retail sales and

20

employment growth value, we did not use AAEGR in model 2. On the other hand model 4 has AAEGR as one of its independent variables, while annual retail sales is omitted in model 4. Both variables have been shown to be statistically very relevant in terms of predicting economic growth values in each county.

Based on the results shown in Table 3, accessibility is found to have considerable impact on employment growth value and total earnings growth value. For model 2, the p-value of AI term is 25%, implying that the probability that accessibility (as in expression 5) has no effect on employment growth is 25%. The positive sign for accessibility index in model 2 makes sense because the index used in model 2 is inversely proportional to the travel time and a high value represents a high level of accessibility. The p-value of the AI term for model 4 is 3%, which is very good. The accessibility index for model 4 has a negative sign because the index used in this model is directly proportional to the travel time and therefore a high value represents a low level of accessibility. Both models have very high R^2 values, which shows a good correlation between the dependent variable and independent variables. The regression analysis results thus show that the level of accessibility has a significant impact on employment and total earnings growth values.

Our model clearly shows that the economic growth is a function of accessibility, among other things, which is related to the transportation system performance measured in terms of travel times. Thus our model, which successfully links travel times to the level of economic growth, depicts the existence of a link between transportation system performance and economic growth. However, it is important to emphasize that this relationship as depicted by our model cannot be carried directly to the individual project level since our model is aggregate in nature.   Thus it is important not to try to translate the results of our model directly to individual projects, but rather to use it as an indicator of the impact of the transportation system on economic growth.

Another important point discussed in Berechman (2001) is with respect to the direction of causality between economic growth and transportation investment. There are many cases where high economic growth creates the need for transportation investment. In these cases, the causality depicted in our model is reversed. According to Berechman (2001) "disregarding such causality possibilities might result in problems of simultaneity in the empirical analysis, which, in turn, will generate wrong estimates". Hence, the macroeconomic type of models similar to the one developed in this paper "actually demonstrate that the patterns of productivity and public investment growth are similar and that this is what the correlation shows." (Berechman (2001). Thus it is very important to recognize this rather complex cause-effect relationship and not to use the predictions of these models as absolute measures of the impact of individual transportation investments on economic growth, but rather as indicators of a pattern of relationship between economic development and the transportation system.

POLICY ANALYSIS

To analyze the policy impacts of the above models, we have conducted a simple sensitivity analysis by increasing or decreasing the travel times while keeping the other variables constant and observing the effects of increased travel time on the level of economic growth as predicted by model 2.

In model 2, we systematically studied the cases when the accessibility in the year 2000 is increased and then decreased by 5 %, 10 % and 15% relative to the current case. The decreased accessibility scenario was considered in order to investigate the likely case that the transportation network might become even more congested than it is today, due to the excess demand and lack of investment. The increased accessibility scenario was considered based on the fact that new transportation investments might occur in the study area in the foreseeable future.
Expression 10 represents employment growth in terms of the model 2 results shown in Table 3.

$$AAEGR=-19.64+0.212*TBP-0.108*TBE- \qquad (10)$$
$$1.43*AAEGR_{adj}+2.53*AAPC_{adj}+1.26*AARSC+11.68*AI$$

Results from the above sensitivity test reveals that, for all the counties in the region, employment growth rate of 2.2%, 4.8% and 7.9% can on average be expected as a result of a 5%, 10% and 15% increase in the level of accessibility, respectively. Similarly, when the level of accessibility was decreased by 5%, 10% and 15% in these counties, the amounts of employment growth rates decreased by 1.9%, 3.6% and 5%, respectively.

Moreover, the results of the analysis of model 2 show that counties closer to major employment locations are more sensitive to changes in the level of accessibility (that is, percent increase/decrease in employment level for varying accessibility indexes was higher for those counties). A transportation investment made in these counties is then more likely to result in higher employment growth rate compared to counties farther away. This is also supported by empirical observations. New Jersey counties that are closer to the major employment location in the study area-that is, New York City-experience relatively higher growth rates. Figure 6 shows a plot of percent employment growth versus increase in the accessibility index differences between 1990 and 2000, for selected counties in the study area (it is a graphical representation of sensitivity analysis).
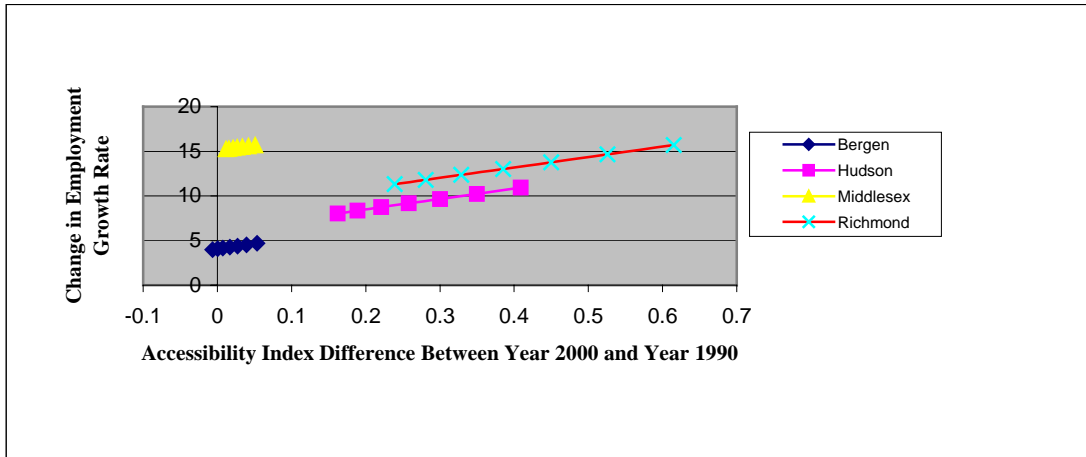
Figure 6. Graphical Representation of the Sensitivity Analysis for Selected Counties.

To understand the effect of increasing travel time- in other words, the decreasing level of service of the transportation system on the total employment and total earnings level- we carried out an analysis using models 2 and 4. To illustrate this, consider the transportation network becoming more congested in 2000 than it is today, due to excess demand and lack of investment, which worsen accessibility (that is, increase the travel time) by 1%, 5%, 10%, 15%, 20% and 25% relative to the present accessibility level.

For this purpose, we computed the new accessibility index differences (between year 2000 and year 1990), each time increasing the future year travel time by 1%, 5%, 10%, 15%, 20% and 25%. By using model 2 (as shown in expression 10) and model 4 (as shown in expression 11), we calculated different levels of total employment and total earnings for the study region (that is, average of all counties in the study region.)

$$AATEC = 9.8 - 0.154*TBP + 0.165*TBE - 0.562*AAEGR_{adj} + 0.8*AAPC_{adj} + 1.034*AAEGR - 0.529*AI \qquad (11)$$

Figures 7 and 8 show the employment and total earnings growth trends for current and future values of travel time for the whole region on average. For the x-axis in figures, we assumed an arbitrary index of 4 for the current travel time values, and then represented the future year increments as 4.01 (for 1% increase), 4.05 (for 5% increase) and so on.
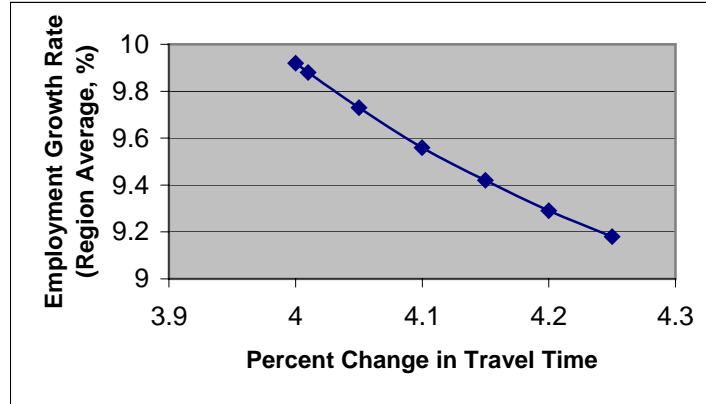
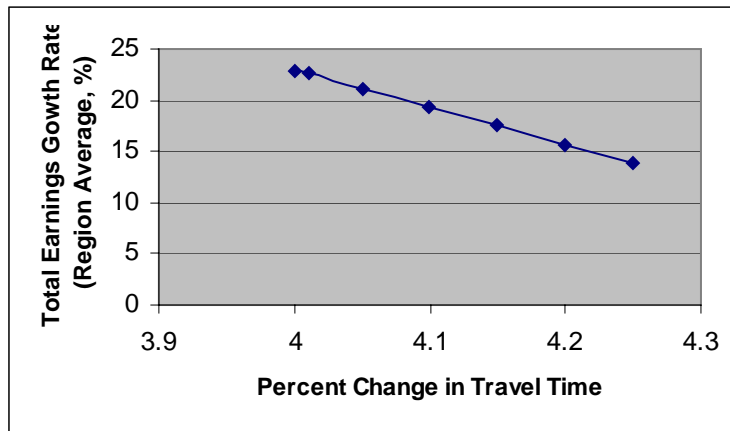**Figure 7. Effect of Increased Travel Time on Employment Level.**

Figure 8. Effect of Increased Travel Time on Total Earnings Level.

In Figure 7 for instance, with the current travel times (represented by the arbitrary accessibility index, 4), the employment growth rate is approximately 9.9%, but when the travel times are increased by 5% (or the arbitrary accessibility index 4.05), the employment growth rate drops to 9.7%.

This analysis reveals that 1% increase in the future year travel time (or accessibility index) will result in a 0.4% decrease in the level of employment growth rate. Similarly, 5%, 10%, 15%, 20 % and 25% increases in travel time will result in 1.9%, 3.6%, 5%, 6.3% and 7.4% employment growth rate reductions, respectively.

To further generalize this analysis, we calculated the elasticity of economic growth with respect to accessibility by using the regression equation for model 2 (as given in expression 10 above) as follows:

$$E_{AI} = \frac{\partial(AAEGR)}{AAEGR} \times \frac{AI}{\partial(AI)} \qquad (12)$$

24

The application of expression 12 to the regression model given in expression 10 results in the following:

$$E_{AI} = \frac{11.68 \times AI}{AAEGR}$$ (13)

Numerical calculation of elasticities for model 2 using expression 13 shows that the elasticity of economic growth follows a general trend depicted by an increase in elasticity for counties closer to the major employment center in the study area, namely, New York City. The average value of elasticity for model 2 is calculated as 0.09 which is also consistent with the output elasticity of public capital in metropolitan areas found in an earlier study (Munnell 1992), which was 0.08 In calculating the average elasticity for the study region, we discarded Queens, since it was an outlier well outside the range of other elasticity values. In addition, 14 out of 18 counties had shown correct trends in terms of economic growth, when compared to the actual trends obtained from census data. According to the elasticity values calculated for model 2, the effect of increasing travel times for counties farther away from the major employment centers is relatively small, compared to the counties close to these major employment centers. This finding has, of course, major implications from a policy-making point of view, since it can dictate where the major investments have to be made. However, one can argue that the areas close to major employment centers are heavily congested anyway, and it is only natural to make more transportation investment in those areas to relieve the existing congestion, not to create more growth.

CONCLUSIONS

The regression analysis results obtained in this study show that improved accessibility has a positive impact on economic development in terms of changes in employment and earnings. Both dependent variables are observed to be highly sensitive to consecutive changes in the level of accessibility.

The similarities and dissimilarities between this study and other studies in the literature with respect to methodologies, variables and final results can be listed as follows:
o In our study, we used a multiple linear regression methodology to estimate the parameters. Similarly, Allen et al. (1993) used a linear regression approach; Boarnet (1996) and Nelson and Moody (2000) used loglinear regression equations; Stephanedes and Eagle (1986) used a time-series approach.
o Our study used employment, population, earnings, retail sales and accessibility index as the variables. Similarly, Allen et al. (1993) also used employment, population, education, debt, school revenues and an overall accessibility index; Boarnet (1996) used employment, capital stock and output (productivity) as the variables; and Nelson and Moody (2000) used per capita demand for a good/service, population, per capita income, and unemployment rate.
o The results of our study showed a significant relationship between economic growth and accessibility. This finding is in agreement with the results of studies by Allen et al. (1993) and Boarnet (1996). Boarnet also stated that even if transportation infrastructure is productive for counties, policy makers ought to be cognizant of the possibility of economic losses outside the immediate project area. However, results

of studies by Nelson and Moody (2000) and Stephanedes and Eagle (1986) showed no overall relationship between highway expenditures and changes in employment levels.

Although the regression models developed in this study can be a good starting point for the policy makers in deciding whether and where to make transportation investments, such major investment decisions require more detailed studies that take into account a wider range of socio-economic factors that could not be included in this study due to its limited scope. However, these models, which clearly depict the relationship between accessibility and economic growth, provide empirical evidence for transportation planners and engineers who work in this field. This, in itself, is an important first step and motivation for further studying this very important relationship.

RECOMMENDATIONS

The following recommendations based on the work conducted in this research project are as follows:

1. The Simplified ESAL table can be automated into an ESAL calculator for use by municipal or county engineers to estimate the ESAL group in the Superpave mixture design system.
2. Develop a training course for municipal or county engineers and consultants to help in the transition from Marshall to Superpave as a mixture design system. The course needs to discuss the commonality between the traditional Marshall mixtures and the requirements of the new Superpave mixtures. The course also needs to explain the connections between Superpave mixture design and the structural pavement design (layer thickness) for selecting the correct mixture and the importance of good construction practices to ensure material and thermal segregation control, sufficient compaction, and adequate layer thickness.
3. Recommend, that for low volume road applications, the average binder film thickness and dust-to-binder ratio be used as a design check to ensure that there is sufficient binder in the mixture.
4. The Marshall mixture and Superpave mixtures used in this research were 9.5mm mixes. Work needs to continue exploring 4.75 mm mixtures for thin overlay applications.
5. Once NCHRP 9-9(1) is completed, work needs to be done to verify these new N_{Design} values for low volume road applications.

ACKNOWLEDGEMENTS

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