ECONOMIC IMPACT ANALYSIS OF HIGHWAY INVESTMENT PROJECTS

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ABSTRACT OF THE THESIS

Economic Impact Analysis of Highway Investment Projects

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In this study a methodology to present an evaluation framework for computing economic impact analysis of highway improvement projects is developed. Another objective is to study the impact of locally implemented highway improvements on the entire transportation network. Accessibility changes of improved locations are also measured to understand the impact of these individual projects.

To illustrate proposed methodology, five major highway construction projects in New Jersey are selected. Capacity improvement due to each project is reflected in the North Jersey Regional Transportation Model Enhanced (NJRTM-E) model by increasing the capacity of the link where the project took place. The NJRTM-E network is run with and without changing the capacity of specific highway links of project locations. These runs present before and after scenarios of improvement projects. The results of this network are processed in the ASSIST-ME/NJCOST software developed for Rutgers Intelligent Transportation System (RITS) Laboratory. Finally benefit-cost ratio of each project is calculated to quantify the economic impact of these projects.

The result of this analysis shows that the majority of the benefits are due to reduction in congestion costs. The analysis discovers that locally implemented highway improvement

solutions affect the entire transportation network. The analysis also shows that accessibility of the region is increased after the implementation of these projects. Future research should be conducted to explain the reasons for extreme change in volumes away from the improvement location.

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Introduction

Traffic congestion is considered as one of the major urban transportation problems. Impacts of traffic congestion are most crucial when volume approach road's capacity traffic. It reduces the mobility, increases transportation cost and also causes pollution. Over the years, the traffic congestion problem has been addressed by a variety of measures such as improving roadway infrastructure, taxation on fuel use, improving or expanding public transport, congestion pricing, traffic control management etc. Highway capacity expansion projects are often suggested as ways to reduce traffic congestion. Usually two different strategies can be applied to solve congestion problems which are demand side strategy and supply side strategy [Rhoads and Shogren (*1*)]. Demand side strategies take a relatively long run view of congestion relief by changing consumers' demand for transportation. In contrast, supply side strategies such as highway improvement projects are intend to meet the current demand immediately by increasing the supply of highway capacity. Capacity improvement solutions may provide only modest congestion reduction benefits over the long run because a significant portion of added capacity is often filled with induced traffic demand caused by increased highway capacity (*1*). In order to alleviate congestion, state and local authorities must achieve a balance between the construction of key, new transportation facilities and the use of advanced technology and also demand management. The policy of building more highways and increasing the capacity on the in-place networks by constructing additional lanes has been favored for many years as congestion mitigation solution. However building new roads or adding lanes to the existing roads are capital-intensive solutions. It is required to rank the proposal of highway investment projects in an order of priority because of fund availability constraint. Different approaches have been used by transportation planners and researchers to evaluate and compare potential transportation improvement projects. Existing methodologies range from single-criteria cost-benefit analysis to multiple criteria and total cost analysis methods [Ozbay et al. (*2*)]. Cost-benefit analysis is the most important and recurring technique of the public investment evaluation. It requires the quantification and comparison of the various benefits and costs generated by a project over time. The effects from the project are first enumerated and classified as benefits and costs. Then, each effect is quantified and expressed in monetary terms using appropriate conversion factors (*3*).

The main objective of this study is to conduct an economic impact analysis of highway improvement projects. In this study cost-benefit analyses are performed on five past highway projects in New Jersey using a comprehensive evaluation framework that measures the dollar value of the output of these projects in a multi-dimensional manner. The proposed economic evaluation framework evaluates the long-term benefits of highway capital investments which applies GIS based software NJCOST and utilizes the most common approach of public investment evaluation namely, cost-benefit analysis. Another purpose of this evaluation technique is to find the network-wide impact of highway investment projects and then compare with the localized impacts. Although an improvement project is initiated to solve the congestion problems of a certain location, it can affect the connected areas. Cost-benefit analysis for the small network or improved road section will capture the localized impact while cost-benefit analysis for the complete transportation network is expected to capture network effects of these same improvement projects. To understand this network-wide impact, the benefit-cost ratio of each project for a large geographic scope is compared. To interpret the change in accessibility causes by improvement project, a simplified form of Hansen's Accessibility Index (*4*) is employed. First the Traffic Analysis Zone (TAZ) is selected along the facility location which is considered as the origin of the selected project. Then different TAZs as destinations are selected to find the accessibility of the origin point with respect to destinations.Destinations are selected within the county where the improvement has taken place and also in neighboring county of the improved highway location. This analysis illustrates the impact of highway improvement on accessibility.

The identification of costs and benefits requires a complex analysis due to the multidimensional impacts of a given transportation project. The prevailing goal of a transportation investment is the improvement of travel conditions which can be defined in terms of multiple criteria (access, time, safety, reliability, etc.). There are, however, additional and broader benefits of transportation projects. Highway transportation offers direct benefits to businesses (e.g., cost reductions in trade, manufacturing, agriculture and increased tourism), and indirectly generates and supports economic growth. In this study, for each selected past highway improvement project, the capacity improvement is quantified using the NJRTM-E model by increasing the capacity of the link where the project took place. The results of NJRTM-E network runs with and without capacity improvements obtained in CUBE are then processed in the ASSIST-ME/NJCOST program developed by RITS lab researchers in the past. Benefits of the projects are estimated by the reductions in various cost categories, such as congestion, vehicle operating, accident, air pollution, and noise and maintenance costs. Final step of the proposed methodology is to conduct the benefit-cost ratio to interpret the impact of highway improvement projects. Accordingly, the proposed methodology combines sound economic theory with the output of a highly detailed transportation demand model for estimating the costs and benefits of selected highway projects.

The ultimate goal of any publicly-funded project is to allocate society's resources efficiently. It is also important to find the most suitable improvement project among different alternatives. It is necessary to ensure that any proposed project promises to return to society in value more than it costs. However decisions about public investments, of course, are made in a political process and cost-benefit analysis does not replace these political decisions. It does inform those decisions and makes the tradeoffs involved in using scarce and finite public resources more transparent.

The remaining chapters of this dissertation are organized as follows. Chapter 2 reviews literature on benefit-cost analysis, other methods of project evaluation, impact of highway improvement projects on accessibility, network-wide impact of highway improvement, detailed description of analysis tool NJCOST and brief introduction of NJRTM-E network. Chapter 3 presents the proposed methodology. Chapter 4 describes the Case studies used in this study. Chapter 5 discusses the results of analysis. Chapter 6 shows conclusion and future research directions. Chapter 7 contains a list of references that helped building this research work.

2 Literature Review

This chapter presents literature review on benefit-cost analysis and other methods of project evaluation. It also reviews the literature which explores the impact of highway improvement projects on accessibility. Finally a detailed description of analysis tool NJCOST and brief introduction of NJRTM-E network are presented here.

2.1 Benefit-Cost Analysis

Several approaches have been developed by researchers and practitioners to evaluate and compare potential transportation improvement projects. The existing methodologies range from single-criteria benefit-cost analysis to multiple criteria models and total cost analysis methods. Benefit-cost analysis is a systematic evaluation of the economic advantages (benefits) and disadvantages (costs) of a set of investment alternatives. Typically, a "Base Case" is compared to one or more Alternatives (which have some significant improvement compared to the Base Case). The analysis evaluates incremental differences between the Base Case and the Alternative(s). In other words, "A cost-benefit analysis tries to answer the question: What additional benefits will result if this Alternative is undertaken, and what additional costs are needed to bring it about?" (*6*). Objective of benefit-cost analysis is to compare the benefits associated with a policy or investment with the costs of implementing the policy or investment. When the sum of the benefits of the project or policy exceeds the costs, then a general economic argument of supporting the action occurs to make the investment or implement the policy.

This method is an economic approach that evaluates the benefits and costs of projects in dollar values and compares the benefit cost ratio (*7-10*). Basically benefit-cost analysis is a framework for social accounting where any benefit or cost that can be measured and monetized is weighed against all other benefits or costs. Benefits generally accrue over a long period of time while capital costs are incurred primarily in the initial years. The primary transportation-related elements that can be monetized are travel time costs, vehicle operating costs, safety costs, ongoing maintenance costs, and remaining capital value (a combination of capital expenditure and salvage value). For some kind of projects, such as bypasses, travel times and safety may improve, but operating costs may increase due to longer travel distances. A properly conducted benefit-cost analysis would indicate whether travel time and safety savings exceed the costs of design, construction, and the long-term increased operating costs.

2.1.1 Important factors of benefit-cost analysis (Time frame, Discount factor)

There are some time-dependent elements that need to be defined and held consistent throughout the analysis, such as (i) analysis time frame, (ii) number of days in a year. According to Reichert (*6*), "Timeframe of cost-benefit analysis should be long enough to capture the majority of benefits, but not so long as to exceed the capabilities to develop good traffic information". Generally a period of 20 years is used as typical for transportation investment project because traffic and demographic information is expected to be available for this timeframe. A typical capacity improvement project in a high-level of commuter traffic generally count 260 days in a year considering the number of weekdays. However it can vary with traffic characteristics and proposed improvement.

Another important factor in cost-benefit analysis is to consider the time value of money by converting the cost costs and benefits that take place in different years into a common year. Because for most of the transportation investment project, costs incurred in initial years, however benefits from the investment accrue over many years into the future after project completion (*6*). Discounting factors are used to convert future costs and benefits that occur in different year into a value for a common year (present value). Recommended discount rates by the U.S. Office of Management and Budget (USOMB) are shown in Table 1(*11)*.

Table 1: Real Discount Rates to be used for Cost-Benefit Analysis

3-Year	5-Year	7-Year	10-Year	20-Year	30-Year
0.9	1.6	1.9	2.4	2.9	2.7

2.1.2 Steps of Benefit-cost analysis

In general, highway improvement projects increase the capacity of existing facilities or systems, and/or improve the safety of existing facilities or systems. According to Reichert (*6*), benefit-cost analysis for highway improvement projects can be conducted in four different following steps.

a) **Planning the analysis and defining its scope:** In this step purpose of the benefit-cost analysis is identified. Sometimes benefit-cost analysis results are used to choose between alternatives. This result can also justify why the preferred alternative is more economically feasible. After identifying the purpose of analysis, it is important to find the available data and how the available data suits the analysis purpose. The next step is to define the base case and proposed alternatives corresponding to the study area. In general highway improvements change travel times, vehicle operating costs, and/or safety characteristics from the base case. So the alternatives should be specified in as much as detail as possible for the purposes of estimating cost (capital and maintenance) and effects on travel time, operating costs and safety. After identifying the alternatives, it is important to identify the time-dependent elements such as, time frame of the analysis, years of construction, number of days in a year (*6*).

b) **Performing engineering analyses of the alternatives**: In engineering analysis, benefit and cost related data of base case and alternatives are identified. Benefit-related data summarize the change in traffic data between base case and improvement alternatives. Change in average annual daily traffic volumes (AADT), change in vehicle-miles traveled (VMT) or change in annual number of crashes for the base case and improvement alternatives are usually considered as Traffic data. Capital costs, annual maintenance cost, operating costs, accident costs, rehabilitation costs etc. are considered as Cost related data

c) **Calculating the present value of project costs and benefits**: After determining the physical benefits of improvement projects, they need to be monetized and aggregated for the analysis period. Next step is to identify the present costs for the base case and alternatives. Total present cost would be the sum of the discounted annual costs found for each year in the analysis timeframe.

d) **Evaluating the results-benefit-cost analysis**: the results of benefit-cost analysis can be shown as benefit-cost ration and/or as net present value. After the future streams of costs and benefits are discounted, the sum of the discounted benefits is divided by the sum of the discounted cost to get the benefit-cost ratio. These results show if the alternative is economically justifies compared to the base case. When multiple alternatives are being considered, and incremental benefit-cost ratio analysis can be used to determine which alternatives are the most economically desirable.

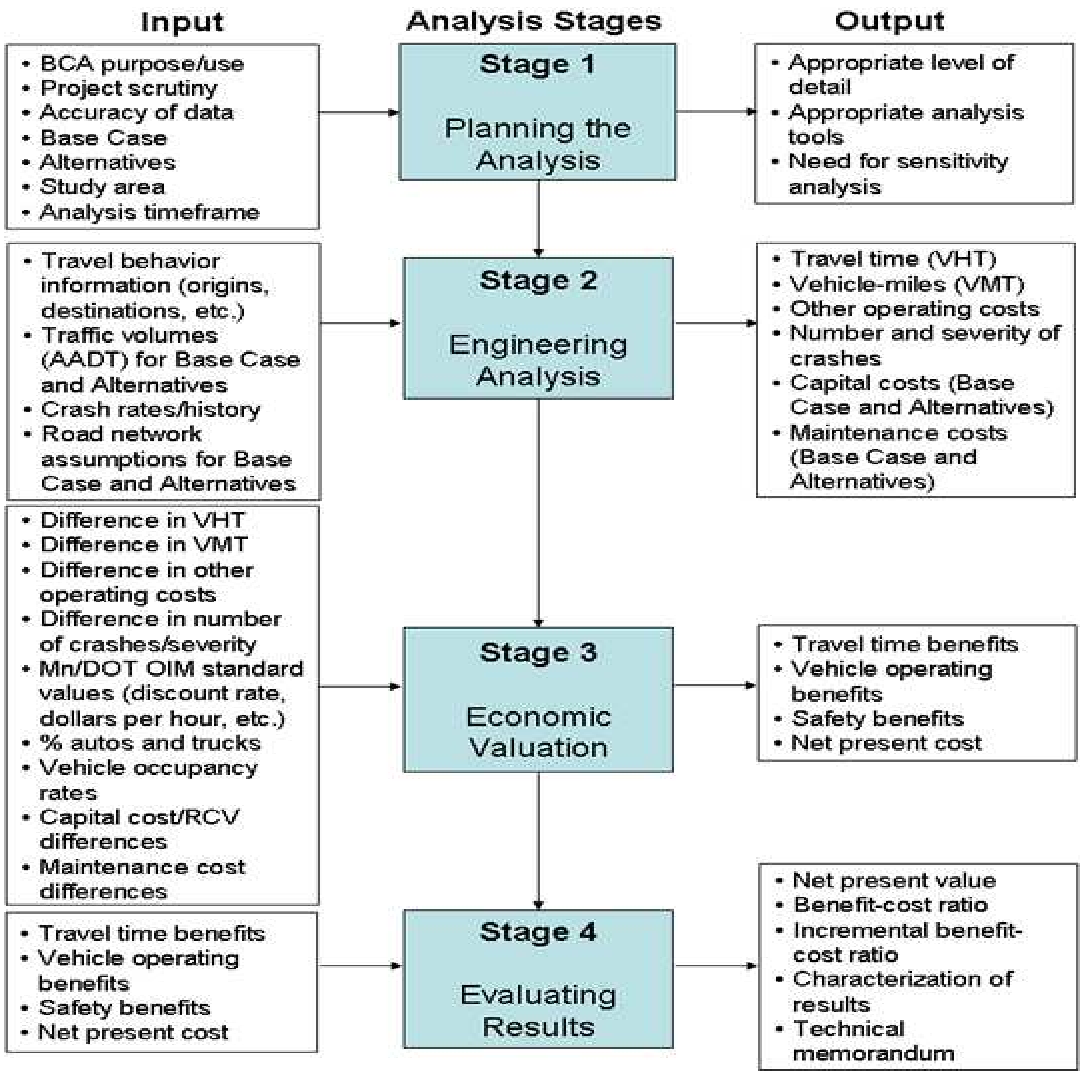

Figure 1: Steps of benefit-cost analysis (*6*)

The formula of calculating benefit-cost (B/C) ratio is presented in Eq. (1)

$$B/C = \frac{PVB}{PVC} = \sum_{t=0}^{T} \frac{B_t / (1+d)^t}{C_t / (1+d)^t} \quad (1)$$

where PVB = Present value of future benefits, PVC = Present value of future costs, d = Discount Rate, t = time of incurrence (year), T = Lifetime of the project or Analysis period (years)

2.1.3 Application of Benefit-Cost analysis

Several studies have used benefit-cost analysis for choosing a preferred alternative highway investment project. For instance a benefit-cost analysis is used for choosing the best alternative transportation investment project for the greater Madison metropolitan area (*12*). This study was commissioned to evaluate several transportation improvement alternatives for the region. Based on the analysis it was concluded that implementing a BRT system in Madison metropolitan area was not an appropriate decision. Based on benefit-cost analysis it was concluded that implementing a BRT system in Madison metropolitan area was inappropriate.

The study by Akan et al. (*13*) used benefit-cost analysis to rank the highway investment project in Turkey. Benefit-cost ratio for each highway improvement proposal was calculated separately and these ratios were ranked in descending order of magnitude. This study showed that car traffic, construction cost per kilometer and length of improved highway were the most salient variables which affected the benefit-cost ratio under the conditions prevailing in Turkey.

Another example of implanting benefit-cost ratio is found in the Northbound US 395 improvement project of Nevada Department of Transportation (NDOT) (*14*). The propose highway improvement project was on US 395 between Moana Lane to I-80.The objective of the proposed highway improvement was to improve operations at local intersection during both the morning and the afternoon peak periods, decreased travel times, and improved safety accommodation. The estimated benefit-cost ratio for the Northbound US 395 improvement was 2.34 which justified the implementation of the project.

Another study was conducted by the Washington Department of Transportation to compare the economic benefits of implementing the proposed Cross Base Highway (SR 704) with the widening of current roads or transit enhancement (*15)*. Three different construction alternatives were proposed for the project. Alternative 1- named as the Build alternative indicated the construction of a 6 mile limited access highway to connect I-5 in the west and SR 7 in the east across Ft. Lewis and Mc Chord Air force base. Alternative 2-widening of SR 7 which included addition of another general purpose traffic lane in both directions of SR 7 between SR 512 in the north and SR 507 in the south. Alternative 3 is the transit enhancement which involved the building of a light rail system from Spanaway in the east to Lakewood in the west. Benefit-cost analysis of this project showed that Alternative 2 had the highest benefit-cost ratio compare to the other alternatives.

Daniel and Haim (*16*), presents a methodology to estimate the benefits of the proposed new Light Rail Transit (LRT) in Tel-Aviv Metropolitan Area (TAMA) in Israel. This study explains that agglomeration economics induced by the proposed project could add a significant amount of additional benefit. Finally a cost-benefit analysis is continued which showed benefit-cost ratio changed to 1.4 from 1.15 for the new project.

To demonstrate the importance of ongoing maintenances, KDOT sponsored a study to estimate the impact of such expenditures on the state's economy (*17*). For this study, a hypothetical drop of 65% in annual funding was used, and examined how that would affect travel conditions and transportation costs-and ultimately also jobs and income in the state. This study shows that a 5-to-1 benefit-cost ratio was associated with ongoing maintenance investment. So the benefit-cost ratio supported the continuation of maintenance funding.

All these studies interpret the application of benefit-cost analysis in transportation field. It can be used for selecting new highway improvement projects or can be used to justify the improvement of existing projects.

2.2 Some other Approaches of Project Evaluation

Even though benefit-cost analysis method has several advantages, urban transportation decision makers rarely use this method due to decision makers' unfamiliarity with this concept, and the complexity of placing monetary values on some of the benefits and costs of transportation projects (e.g., accident reductions, commuting time saved, temporary disruptions) (*18-19*). To address some of these concerns DeCorda-Souza *et al*. (*19*) proposed a total cost analysis to compare alternatives across modes, which may be more useful for decision-makers. This analysis includes travel time, vehicle operating and accident costs.

Other methods namely multiple criteria methods developed to select the most beneficial projects draw upon several approaches. One approach, the scoring method, ranks projects with respect to different objectives, where each objective is assigned a weight and each project is scored with respect to each of the objectives. Then each project is then ranked by score (*20-22*). The main drawbacks of this method are the inability to explicitly address resource constraints and compensatory bias (*19*). A second approach applies mathematical programming models, such as multi-attribute/objective decision making, goal programming and analytical hierarchy process. In this approach, a variety of objectives and resource restrictions are considered simultaneously (*23-26*). The main discrepancy of this approach is the need for crisp data to get meaningful results. Given the high level of uncertainty associated with transportation projects, decision makers typically refrain from such complex techniques (*19*). A third approach, Analytical Hierarchy Process, was developed to include criteria that are not measurable in an absolute sense. In this approach, subjective judgments enter into the evaluation process (*27-29*). This approach is most suitable when optimization is not pursued, resources are not restricted, and interdependencies do not exist.

Life Cycle Cost Analysis (LCCA) is one of the most widely used techniques applied for decision-making in transportation. LCCA is a systematic process for evaluating public projects that generate various impacts over long periods of time. The process is performed by summing up the monetary values of all benefits and costs at their respective time of occurrence throughout the analysis period. These are then converted into a common time dimension so that different alternatives can be compared with respect to a common metric.

Basically all project evaluation techniques include questions relating to a broad definition of effectiveness, the efficiency of resource allocation, the equitable distribution of resources, and the feasibility of implementation.

2.3 Network-Wide Impact of Transportation Investment

Over the last decade numerous studies have been conducted to find the impact of transportation infrastructure development. The major objectives of these studies have been to estimate the returns of transportation investments by type (e.g., highway or public transit) and by geographical level (e.g., national, state). Munnell (*30)* examined spillover effects by hypothesizing that highway public capital creates positive cross-state spillovers. She argued that this could occur when infrastructure investments in one state benefit people in others. Eakin and Schwartz (*31*) have studied similar effects and measured the indirect effect of highway capital investment on neighboring states. However, they have rejected the hypothesis that highway capital has positive output spillovers. In fact, in some of their specifications, the spillover parameter was significantly negative. Boarnet (*32*) has examined how highway investments redistribute economic activity, by dividing the economic impacts of transportation infrastructure into a direct effect (impact near a street or a highway) and indirect effect (any impact that occurs at locations more distant from the highway corridor). He concluded that the direct and indirect effects were equal in magnitude with opposing signs.

Even though most transportation policies are local, their influence often spread out beyond the area of application, as discussed in the previous sections. Responding to policies, traffic will shift from the impacted part of the network to other areas, and the intensity of the shift will depend on several factors, such as road characteristics, demand structure, and network configuration (*33*). Thus, quantification of changes in the transportation costs after the capacity expansion is crucial for policy planners to determine the possible benefits from capacity expansion projects, and select the projects that are most likely to generate highest benefits.

Most of the time highway improvement project is implemented based on the requirements of the area where the road itself is located. However, sometimes this local improvement can also affect the entire transportation network. Benefit-cost analysis is traditionally applied to evaluate the highway investment projects. However, no study has discussed the direct difference between doing the cost-benefit analysis for facility based (small-network or around the improved location) versus entire transportation network based analysis. Few studies have discussed the shortcoming of doing only facility based analysis. For instance Cohen (*34*) considers that "'wider' benefits refer to the "benefits beyond the geographic region in which the investment is undertaken." Another study states that "localized planning approach should be improved upon, as it does not consider system wide impacts resulting from improvement projects. While implementing local solutions may result in localized benefits, these solutions may have limited, negligible or even adverse system-wide effects" (*35*), According to this study, planning approach should be focused on a comprehensive system-wide approach for identifying critical infrastructure and evaluating network performance. The study by Vickerman (*36*) explains that, "Consideration of network effects may increase or decrease the benefits relative to the measurement of benefits for a single link. It is important to consider the true net effect because as redistribution of activities are a substantial part of the highway improvement changes. In some cases increase in demand on undeveloped links in the network leads to loss of benefits on such links which may outweigh a significant part of the gains on the improved link".

Basically the literature review cited above initiate to think about network wide impacts of highway improvement projects. Conducting cost-benefit analysis for entire network rather than doing it only for the improved road section will be more representative. Some projects may show local benefits but induced demand from this improvement may cause congestion to connected routes. Consequence of these excessive congestion cost can overweigh the expected benefits of a small highway improvement. Cost-benefit analysis is crucial for the purpose of project evaluation. So cost-benefit analysis of the entire network will yield a more beneficial outcome.

2.4 Highway Improvement Project and Accessibility

2.4.1 Review on Accessibility Index

In the literature, there exist many different accessibility indexes to assess the performances of transportation system. A popular accessibility measure in Hansen's Accessibility Index [Hansen (*4*)], which measures the accessibility of a location by incorporating its attractiveness and distance to other locations. The equation of Hansen's Accessibility Index is presented below,

$$A_i = \frac{\sum_{j=1}^{n} W_j \cdot e^{-\beta \cdot c_{ij}}}{\sum_{j=1}^{n} W_j} \tag{2}$$

Where A_i = Accessibility of zone I to opportunities in zone *j* for *j* =1, ….n; W_j = measure of attractiveness of zone *j;* and c_{ij} = cost of travel from zone i to zone j (represented by travel time, distance, and so on). Measure of attractiveness can be zonal employment, retail employment, household characteristics (such as income), or population.

Ingram (*37*) proposed a measure, sometimes called integral accessibility is shown in Eq. (3);

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

Where A_i = integral accessibility at ith point; and d_{ij} = relative accessibility of point *j* with respect to point *i* (minutes). This accessibility index is found simply by calculating the total distance of a location to all other locations.

According to Allen et al. (*38*) concept of accessibility is generally interpreted as a measure of the effort (or ease) of overcoming spatial separation between two points. According to this concept, 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;

$$A_i = \frac{1}{N-1}\sum_{j=1}^{N} d_{ij} \tag{4}$$

Where N_i = number of zones

Black and Conroy (*39*) 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 presented below,

$$K_i = \int_0^T A(t)dt \tag{5}$$

According to Ozbay et al. (*33*) accessibility is combination of travel time and monetary costs, knows as generalized travel costs, adjusted for the type of modes used. To a certain extent, accessibility costs are endogenous variables in the decision process of potential employees. That is, given their location, factors such as mode choice, time of departure, car ownership and car utilization are used by individuals to effectuate their travel times and costs. On the other hand mode availability, bus and train headways, fares and road tolls are largely exogenous. In this analytical model both endogenous and exogenous variables have included. According to this model the level of accessibility between residential and employment location i and j, respectively measured in units of weighted travel time is expressed as a function of several variables. The accessibility function is as follows;

$$T_{ij} = f(\, w_{ij}^{m}\, t_{ij}^{m}, d_{ij}, C_i^H, \mathrm{Y}_i^H) \tag{6}$$

Where T_{ij} = accessibility between residential and employment locations i and j; t_{ij}^{m} = travel times by mode, weighted by the proportions of people using that mode between these locations; d_{ij} = time of departure; C_{i}^{H} = car ownership by households (at residential location i); Y_{i}^{H} = household's income level

2.4.2 Impacts of Highway Improvement Project on Accessibility

Highway improvement projects can change the accessibility of the region where improvement takes place. Because according to the existing literature on accessibility index, accessibility level of a region is determined by the transportation cost, travel time or overall performance level of the transportation system. However any highway improvement project tries to improve the performance of transportation system and in turn accessibility of that region can be changed.

Banister and Berechman (*3*) depicts a general framework that describes the relationship between the transportation system and economic growth. According to this framework, accessibility is improved as a result of improvement of the existing transportation system. Improved accessibility, in turn, changes the travel and land use patterns and causes economic growth.

Ozbay *et al.* *(40)* examined the effect of improved accessibility from transport investments on the local employment in the New York / New Jersey metropolitan area. Their analysis indicated that changes in accessibility costs had a detectable effect on employment. Accessibility was found to be affected more by private car travel times, rather than public transit travel times. The magnitude of the estimated net employment effect was modest, namely, a 10% increase in accessibility results in a 0.54% increase in new employment.

Literature review shows that there is a linkage between accessibility (transportation) and economic development of the region studied. However, the impact of highway improvements on accessibility change is not clearly specified in existing literatures

2.5 Description of NJCOST Software

NJCOST employs ArcGIS in the Visual Basic .NET environment. The costs of a trip between a selected Origin-Destination (O-D) pair are calculated using the constrained k-shortest path algorithm that uses C programming language. In the developed GIS-based NJCOST tool, the origin and/or destination of a trip can consist of the following options:

a. Single node.
b. User-defined set of nodes within Traffic Analysis Zones (TAZ) or one TAZ for each origin and destination.
c. County-to-County selection, i.e. user-defined set of nodes within each county (one county for each origin and destination).
d. Intra-County selection i.e. user-defined set of nodes within a county (same county for the origin and destination).
e. Network-wide selection - user-defined set of nodes within the whole network at hand.

2.5.1 Cost Functions used in NJCOST

The cost reduction categories used in NJCOST are (1) vehicle-operating, (2) travel time and congestion, (3) accident, (4) air-pollution, (5) noise, and (6) maintenance costs. Reductions in each cost category attributable to a project were estimated using data obtained from NJDOT and other state and national sources. Data on vehicle operating costs, accident costs, and infrastructure costs are NJ-specific. STATA software is used to estimate the parameters of each cost function. Congestion and environmental costs, however, were based on relevant studies in the literature. The parameters of the cost functions were modified to reflect NJ-specific conditions. The individual cost reduction functions are discussed below.

2.5.2 Vehicle Operating Costs

Vehicle operating costs are directly borne by drivers. These costs are affected by many factors, such as road design, type of the vehicle, environmental conditions, and flow speed of traffic. In this study, vehicle operating costs depend on depreciation cost, cost of fuel, oil, tires, insurance, and parking/tolls. Depreciation cost is itself a function of mileage and vehicle age; other costs are unit costs per mile. In this study, the depreciation cost function estimated by Ozbay *et al*. (*41*) is used and the functions are shown in Table 8. The other cost categories, namely, cost of fuel, oil, tires, insurance, parking and tolls are obtained from appropriate AAA report (*42*) and USDOT report (*43*). The unit operating costs given in Table 2 are in 2005 dollars.

Table 2: Operating Costs (in 2005 dollars) (*42, 43*)

Operating Expenses	Unit Costs
Gas & oil	0.087 ($/mile)
Maintenance	0.056 ($/mile)
Tires	0.0064 ($/mile)
Insurance Cost	1,370($/year)
Parking and Tolls	0.021 ($/mile)

2.5.3 Congestion Costs

Congestion cost is defined as the time-loss due to traffic conditions and driver's discomfort, both of which are a function of increasing volume to capacity ratios. Specifically,

- Time loss can be determined through the use of a travel time function. Its value depends on the distance between any OD pairs (d), traffic volume (Q) and roadway capacity (C).
- Users' characteristics: Users traveling in a highway network are not homogeneous with respect to their value of time.

Since all these cost categories are directly related to travel time, the monetary value of time (VOT) is a crucial determinant of cost changes. Depending on the mode used by the traveler, travel time costs may include time devoted to waiting, accessing vehicles, as well as actual travel. In a study of congestion costs in Boston and Portland areas, Apogee Research estimated congestion costs using VOT values based on 50% of the average wage rate for work trips and 25% for other trip purposes (*44*). Based on a review of international studies, K. Gwilliam (*45*) concluded that work travel time should be valued at 100% wage rate, whereas non-work travel time should be valued at 30% of the hourly wage rate, given the absence of superior local data. Similarly, the USDOT (*46*) suggests VOT values between 50% and 100% of the hourly wage rate depending on travel type (personal, business). In these studies, user characteristics, mode of travel, or time of day choices are not included in the VOT estimation. To address these issues, stated preference surveys are conducted in some studies to estimate VOT for different modes and trip types (*47-49*).

In this study, VOT ranges are adopted based on average hourly wages as recommended by the USDOT (*43*). Following the USDOT (*43*), two vehicle types are assumed: passenger cars and trucks. For passenger cars, the VOT range, based on the hourly wage, is assumed to be between 80% and 120% of the average hourly wage within peak period, and between 35% and 60% of the average hourly wage within off-peak periods, respectively. For trucks, the VOT range, based on the hourly wage, is assumed to be 100% within both off-peak and peak periods.

U.S. Department of Labor (*50*) reported average hourly wages for all occupations in New Jersey. The report indicates that, in 2007, the average hourly wage for all occupations was $22.64 per hour. The hourly wage in trucking was $19.90 per hour. Table 3 shows the VOT ranges, as suggested by the USDOT (*50*), used in our analysis.

Table 3: Value of Time Ranges (*50*)

Time Period	Passenger Cars	Trucks
Peak	$18.1 - $27.2	$19.9
Off- Peak	$7.9 - $13.6	$19.9

The Bureau of Public Roads travel time function was used to calculate time loss. Thus, the total cost of congestion between a given OD pair can be calculated by the time loss of one driver along the route, multiplied by total traffic volume (Q) and the average value of time (VOT).

2.5.4 Accident Costs

Accident costs are the economic value of damages caused by vehicle accidents/incidents. These costs can be classified in two major groups: (1) cost of foregone production and consumption, which can be converted into monetary values, and (2) life-injury damages, which involves more complex techniques to convert into monetary values. Costs associated with these two categories are given in Table 4.

Table 4: Accident Cost Categories (70)

Pure Economic Costs	
Major costs	Description
Medically related costs	Hospital, Physician, Rehabilitation, Prescription
Emergency services costs	Police, Fire, ambulance, helicopter services, incident management services
Administrative and legal costs	Vehicle repair and replacement, damage to the transportation infrastructure
Life Injury Costs	
Employer costs	Wages paid to co-workers and supervisors to recruit and train replacement for disabled workers, repair damaged company vehicles, productivity losses due to inefficient start-up of substitute workers
Lost productivity costs	Wages, fringes, household work, earnings lost by family and friends caring for the injured
Quality of life costs	Costs due to pain, suffering, death and injury
Travel delay costs	Productivity loss by people stuck in crash related traffic jams

The accident cost function estimates the number of accidents that occur over a period of time, and converts the estimated number of accidents into a dollar value by multiplying the number of accidents by their unit cost values. The cost of any specific accident varies of course with individual circumstances. However, similar accidents typically have costs that fall within the same range.

Accidents were categorized as fatal, injury and property damage accidents. Accident occurrence rate functions for each accident type were developed using the traffic accident database of New Jersey. Historical data obtained from NJDOT show that annual accident rates, by accident type, are closely related to traffic volume and roadway geometry.

Traffic volume is represented by the average annual daily traffic. The roadway geometry of a highway section is based on its engineering design. There are various features of a roadway geometric design that closely affect the likelihood of an accident occurrence. However, these variables are too detailed to be considered in a given function. Thus, highways were classified on the basis of their functional type, namely Interstate, freeway-expressway and local-arterial-collector. It was assumed that each highway type has its unique roadway design features. This classification makes it possible to work with only two variables: road length and number of lanes. There are three accident occurrence rate functions for each accident type for each of the three highway functional types. Hence, nine different functions were developed. Regression analysis was used to estimate these functions. The available data consists of detailed accident summaries for the years 1991 to 1995 in New Jersey. For each highway functional type, the number of accidents in a given year is reported.

The unit cost of each type of accident directly affects the cost estimates. The National Safety Council (*51*) reported the average unit cost per person for three accident types, as shown in Table 5. These values are comprehensive costs that include a measure of the value of lost quality of life which was obtained through empirical studies based on observed willingness to pay by individuals to reduce safety and health risks.

Table 5: Average Comprehensive Cost per Person by Accident Type (*51*)

Accident Type	**Cost**
Death	$4,100,000
Incapacitating Injury	$208,500
Non-incapacitating Injury	$53,200
Possible Injury	$25,300
Property Damage	$2,300

Accident cost estimation is not exact, it can only be approximated. The studies in the relevant literature show varying unit costs for accidents. A NHTSA study (*52*) reports the lifetime economic cost of each fatality as $977,000. Over 80% of this amount is attributable to lost workplace and household productivity. The same study reports that the cost of each critically injured survivor is $1.1 million (*52*). A study by FHWA (*53*) reported the comprehensive cost of each accident by severity, as shown in Table 6.

Table 6: Average Comprehensive Cost by Accident Type (*53*)

Accident Type	Cost
Fatal	$3,673,732
Incapacitating	$254,335
Evident	$50,867
Possible	$26,847
Property Damage	$2,826

Note: All costs are in 2008 dollars, converted from 1994 values using 2.5% discount rate.

A recent poll conducted by AASHTO (*54*) reported accident costs by severity. The reported figures shown in Table7 reflect the average accident costs used by 24 states for prioritizing safety projects.

Table 7: Average Cost by Accident Type (*54*)

Accident Type	Cost
Fatality	$2,435,134
Major Injury	$483,667
Incapacitating Injury	$245,815
Minor Injury	$64,400
Non-incapacitating Evident Injury	$46,328
Injury	$59,898
Possible or Unknown injury	$23,837
Property Damage	$6,142

In this analysis, the unit accident costs reported by the FHWA (*53*) are used. In order to align the cost estimates based on the accident types available in NJDOT accident database, accident types are regrouped in FHWA (*53*) into fatality, injury (incapacitating) and property damage accidents.

The accident cost functions are presented in Table 8. These functions are based on unit accident cost for each accident type. The accident cost functions used in this study were first developed by Ozbay *et al*. (*55*) and later improved by Ozbay *et al*. (*56, 57*) with a new accident database. The statistical results of the estimation of accident occurrence rate functions can be found in Ozbay *et al*. (*57*).

2.5.5 Environmental Costs

Environmental costs due to highway transportation are categorized as air pollution and noise pollution costs.

2.5.5.1 Air Pollution Costs

Highway transportation accounts for the air pollution due to the release of pollutants during motor vehicle operations. This occurs either through the direct emission of the pollutants from the vehicles, or the resulting chemical reactions of the emitted pollutants with each other and/or with the existent materials in the atmosphere. The pollutants included in estimating air pollution costs in this study are volatile organic compounds (VOC), carbon monoxide (CO), nitrogen oxide (NO_x), and particulate matters (PM_{10}).

Estimating the costs attributable to highway air pollution is not a straightforward task, since there are no reliable methods to precisely identify and quantify the origins of the existing air pollution levels. The constraints for estimating the costs attributable to air pollution are listed as follows:

Air pollution can be *local*, *trans-boundary* or *global*. As the range of its influence broadens, the cost generated increases, and after a certain point the full cost impact becomes difficult to estimate.

Air pollution effects are typically chronic in nature. Namely, unless the pollution level is at toxic levels, the damage imposed on human health, agricultural products and materials may be detectable only after years of exposure.

Even if the influence of specific sources of air pollution could be isolated with precision, quantifying the contribution of highway transportation requires several assumptions. Emission rates depend on multiple factors, such as topographical and climatic conditions of the region, vehicle properties, vehicle speed, acceleration and deceleration, fuel type, *etc*. The widely used estimation model is available in US MOBILE software, which requires, as inputs, the above listed factors. Based on the input values, the program estimates emissions of each pollutant. However, the accuracy of this specific model and the other current models are negotiable [Small and Kazimi *(58)*].

Cost values attributable to differing levels of air pollution require a detailed investigation and an evaluation of people's preferences and their willingness to pay in order to mitigate or avoid these adverse effects.

There is an extensive literature that attempts to measure the costs of air pollution (e.g., Small (*59*), Small and Kazimi (*58*), Mayeres et al. (*47*). There are three ways of estimating the costs of air pollution: *Direct estimation of damages*, *hedonic price measurement* (relates price changes, demand, and air quality levels) and *preference of policymakers* (pollution costs are inferred from the costs of meeting pollution regulations) *(58)*.

Small and Kazimi *(58)* adopt the direct estimation of damages method to measure the unit costs of each pollutant. The study differentiates the resulting damages in three categories: *mortality from particulates*, *morbidity from particulates* and *morbidity from ozone*. It is assumed that human health costs are the dominant portion of costs due to air pollution rather than the damage to agriculture or materials. *Particulate Matter* (PM10) which is both directly emitted and indirectly generated by the chemical reaction of *VOC*, *NO*x, and *SO*x, is assumed to be the major cause of health damage costs. Ozone (O3) formation is attributed to the chemical reaction between *VOC* and *NO*x. In this study, the unit cost values suggested by Small and Kazimi *(58)* is used. The air pollution cost function is given in Table 8.

2.5.5.2 Noise Costs

The external costs of noise are most commonly estimated as the rate of depreciation in the value of residential units located at various distances from highways. Presumably, the closer a house to the highway the more the disamenity of noise will be capitalized in the value of that house. While there are many other factors that are also capitalized in housing values, “closeness” is most often utilized as the major variable explaining the effect of noise levels. The Noise Depreciation Sensitivity Index (*NDSI*) as given in Nelson (*60*) is defined as the ratio of the percentage reduction in housing value due to a unit change in the noise level. Nelson (*60*) suggests the value of *0.40*% for *NDSI*.

The noise cost function is given in Table 8. The function indicates that whenever the ambient noise level at a certain distance from the highway exceeds 50 decibels, it causes a reduction in home values of houses. Thus, the change in total noise cost depends both on the noise level and on the house value. Detailed information is presented in Ozbay *et al.* (*55*).

2.5.6 Maintenance Costs

Roadway infrastructure costs are equated in this analysis with resurfacing costs. A total of 61 resurfacing projects in New Jersey, between 2005 and 2006 were considered. The data consisted of average number of lanes, length in miles and total project costs. This data did not include roadway traffic volume. Therefore, a simple resurfacing cost function based on number of lanes and length was developed. Table 8 shows the infrastructure cost function of roadway maintenance (resurfacing).

Table 8: Cost Functions (70)

Cost	**Total Cost Function**	**Variable Definition**	**Data Sources**
Vehicle Operating	$C_{opr} = 7208.73 + 0.12(m/a) + 2783.3a + 0.143m$	a: Vehicle age (years)	AAA [42], USDOT [43], KBB [61]
Congestion	$C_{cong} = \begin{cases} Q.\frac{d_{a,b}}{V_o}.\left(1+0.15\left(\frac{Q}{C}\right)^4\right).VOT & \text{if } Q \le C \\ Q.\frac{d_{a,b}}{V_o}.\left(1+0.15\left(\frac{Q}{C}\right)^4\right).VOT+Q.\left(\frac{Q}{C}-1\right).\frac{VOT}{2} & \text{if } Q > C \end{cases}$	Q = Volume (veh/hr) d = Distance (mile) C = Capacity (veh/hr) VOT = Value of time ($/hr) V_o = Free flow speed (mph)	Mun [62] Small and Chu [63]
Accident	*Category 1*: Interstate-freeway: $C_{acc} = 127.5Q^{0.77}.M^{0.76}.L^{0.53} + 114.75Q^{0.85}.M^{0.75}.L^{0.49} + 198{,}900Q^{0.17}.M^{0.42}.L^{0.45}$ *Category 2*: principal arterial: $C_{acc} = 178.5Q^{0.58}.M^{0.69}.L^{0.43} + 18{,}359Q^{0.45}.M^{0.63}.L^{0.47}$ *Category 3*: arterial-collector-local road: $C_{acc} = 229.5Q^{0.58}.M^{0.77}.L^{0.77} + 9{,}179.96Q^{0.74}.M^{0.81}.L^{0.75}$	Q = Volume (veh/day) M = Path length (miles) L = no of lanes	FHWA [64] USDOT [65]
Air pollution	$TC_{air} = Q(0.01094 + 0.2155F)$ where; $F = 0.0723 - 0.00312V + 5.403x10^{-5}V^2$	F = Fuel consumption at cruising speed (gl/mile) V = Average speed (mph) Q = Volume (veh/hr)	EPA [66]
Noise	$C_{noise} = 2\int_{r_1=50}^{r_2=r_{max}} (L_{eq} - 50)DW_{avg}\frac{RD}{5280}dr$ where; $K = K_{car} + K_{truck}$ $K = \frac{F_c}{V_c}\left(V_c^{4.174}.10^{0.115} + 10^{5.03F_{ac}+(1-F_{ac})6.7}\right) + \frac{F_{tr}}{V_{tr}}\left(V_{tr}^{3.588}.10^{2.102} + 10^{7.43F_{atr}+(1-F_{atr})7.4}\right)$ $L_{eq} = 10\log(Q) + 10\log(K) - 10\log(r) + 1.14$	Q = Volume (veh/day) r = distance to highway K = Noise-energy emis. K_{car} = Auto emission K_{truck} = Truck emission F_c = % of autos, F_{tr} = % of trucks F_{ac} =% const. speed autos F_{atr}=% of const. speed tr. V_c = Auto Speed (mph) V_{tr} = Truck Speed (mph)	Delucchi and Hsu [67]
Maint.	$C_M = 800{,}950N^{0.384}L^{0.403}$	N: Number of lanes L: Length of project (miles) T: Time between each resurfacing cycles (hour) t: Travel time of one additional vehicle (hour)	Ozbay et al. [55]

2.6 Description of NJRTM-E Network

The NJRTM network, shown in Figure 2, is a standard four-step transportation model that uses CUBE, FORTRAN and TP+ software. The model area consists of the thirteen county North Jersey region; external stations are used to represent travel to and from places outside the region including New York City. The model is a tool that is used to help with analyzing projects, developing the long-range plan, and determining compliance with air quality conformity standards. The model was largely developed in the late 1980's by the New Jersey Department of Transportation (NJDOT) and subsequently enhanced by the NJTPA and NJDOT in various stages since then. The NJRTM network has 1377 traffic analysis zones and 74 external stations (*68*).

The highway network includes most arterials (major and minor), but does not include many local roads. The model was revalidated in April 2006 using observed traffic data from 2000 (including traffic counts and travel time) and socioeconomic data. This network has undergone major improvements in the last year, and now it has more traffic information and GIS-based capabilities than its previous version.

The NJRTM model was improved and the North Jersey Regional Transportation Model - Enhanced (NJRTM-E) by NJTPA and its consultants to produce a fully functioning transportation forecasting tool that is comprehensive and powerful enough to fulfill the regional modeling needs of all major transportation agencies in the region (*68*).

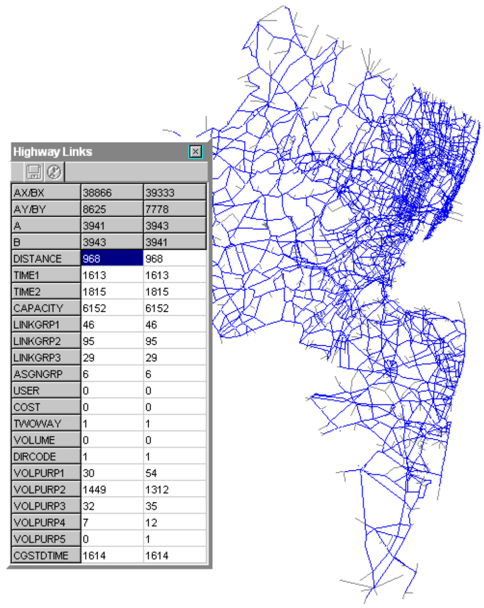

Figure 2: North Jersey Regional Transportation Model (NJRTM-E) (*68*)

"In 2008, NJTPA completed a major upgrade to the region's travel demand model. The result is the North Jersey Regional Transportation Model-Enhanced (NJRTM-E). This model was developed with the participation of NJDOT and NJ Transit and fully incorporates the multi-modal nature of the transportation issues facing northern New Jersey. The model is comprehensive and sufficiently powerful to be used by all major transportation agencies in the region. It runs on Citilabs software products CUBE (as an interface), and Voyager with additional FORTRAN programs used for mode choice and reporting elements" (*68*).

"Cube, the main tool used for NJRTM-E model, is powerful and comprehensive software developed by Citilabs. A Cube modeling module, Cube Voyager combines the latest in Citilabs' technologies for the forecasting of personal travel. Cube Voyager uses a modular and script-based structure allowing the incorporation of any model methodology ranging from standard four-step models, to discrete choice to activity-based approaches. Advanced methodologies provide junction-based capacity restraint for highway analysis and discrete choice multipath transit path building and assignment. Cube Voyager includes highly flexible network and matrix calculators for the calculation of travel demand and for the detailed comparison of scenarios." (*69*). User interface of the NJRTM-E model in CUBE can be seen in Figure 5. The NJRTM-E is a standard four-step transportation model. The four steps are (*69*).

i. Trip generation, where the number of trip origins and destinations are estimated;
ii. Trip distribution, where trip origins are matched with trip destinations;
iii. Mode choice, where a travel mode (e.g., single occupant vehicle, transit) is assigned to each trip;
iv. Trip assignment, where the route that each trip takes from each origin to destination is estimated.

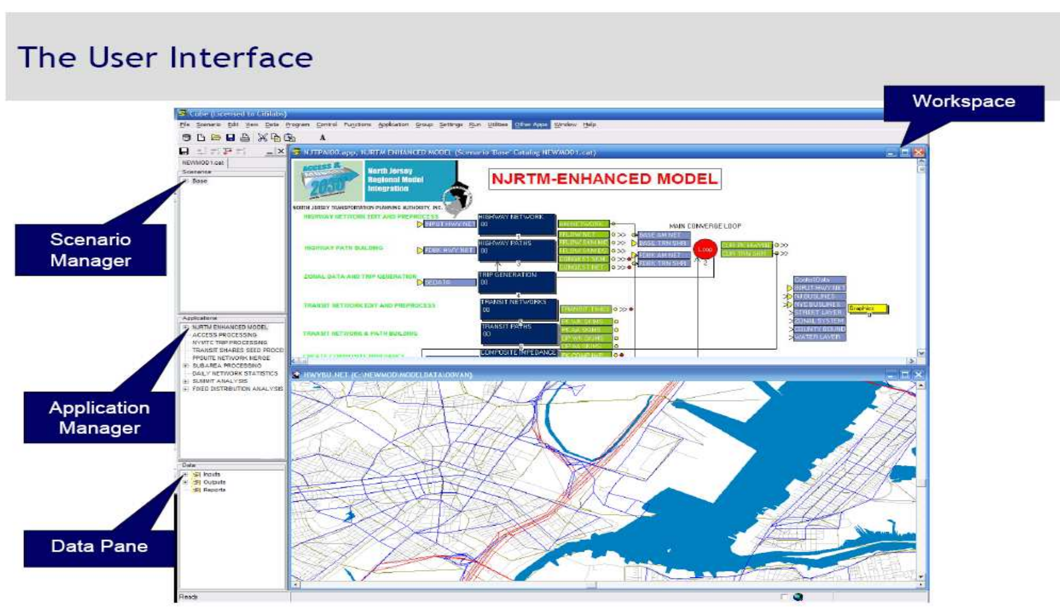

Figure 3: User Interface of NJRTM-E Model (*68*)

"The new NJRTM-E model's includes trips to the NY area as well, which provides more realistic picture of the commuting trends in the region. The NJRTM-E model now includes a detailed highway network with 6.5 million residents and 23,000 miles of highway network in CUBE (Figure 4)".

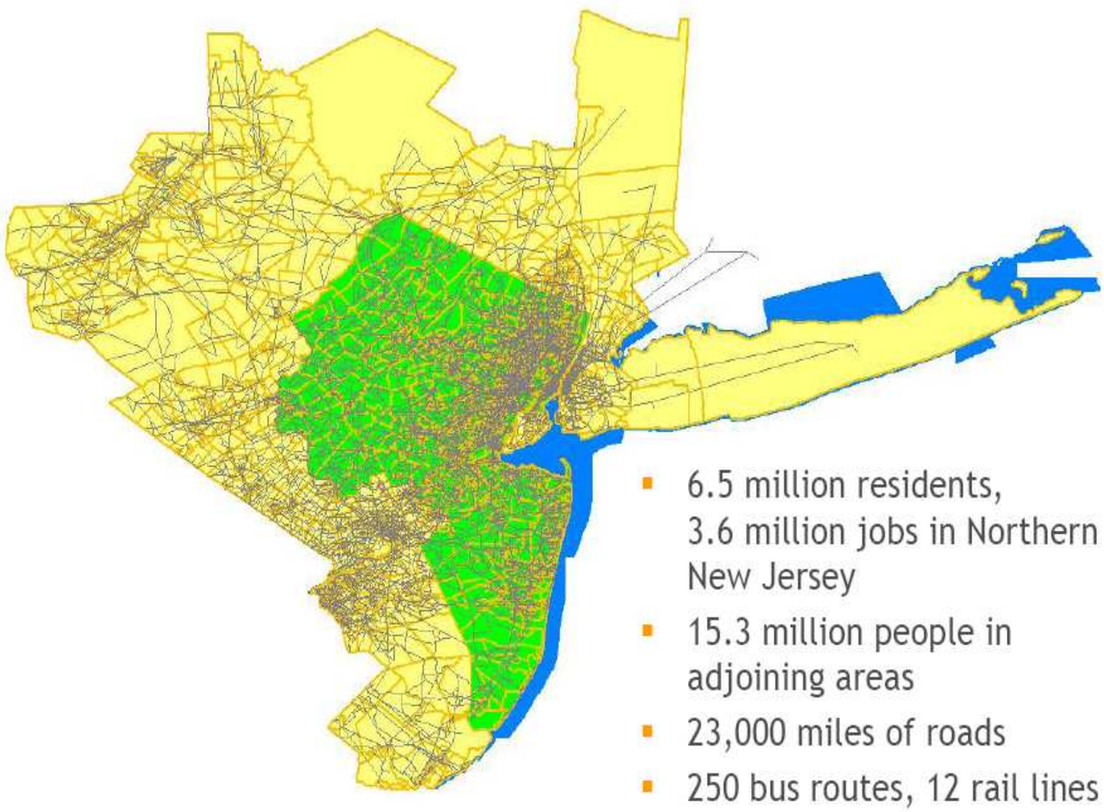

Figure 4: NJRTM-E Region in Cube (*69*)

3. Methodology

In this study, benefit-cost analysis is performed on past highway projects in New Jersey using the proposed evaluation framework. To implement the proposed methodological framework, five major highway construction/improvement projects in New Jersey are selected. Detailed information about the improvement projects are also available for instance total construction cost of each project, project start and completion date, project lead, increased number of lanes or any change in roadway geometry of these projects etc. The steps of proposed methodological framework of this study are presented below:

1) **Transportation Planning Stage**

In this step, transportation planning model named The North Jersey Regional Transportation Model-Enhanced (NJRTM-E) is used to implement the highway improvement change for the selected projects. This model can estimate the changes in traffic flows that occur on both local and network level as a result of highway improvement. For each selected past highway improvement project, the capacity improvement is reflected in the NJRTM-E CUBE model by increasing the capacity of the link where the project took place. It is difficult to quantify the exact capacity change from improvement work. Roadway capacity can be improved in different ways such as by increasing the number of lanes, increasing shoulder length, removing guardrails, increasing the lane width and changing the roadway geometry (vertical or horizontal alignment). Therefore, the capacity improvement factor, denoted by α_{cap} in this study, is subject to sensitivity analysis. The NJRTM-E network is based on 2000 traffic levels. For projects that were undertaken after year 2000, an annual traffic growth rate of 1 percent is used to populate the origin-destination (OD) demand for future years. Using the CUBE software, capacity of any highway link of NJRTM-E network can be changed according to the requirements. In this study, the NJRTM-E network is run with and without changing the capacity of specific highway links where the projects took place. These runs give the before and after scenario of selected highway improvement projects. The output results of CUBE model determine the change in traffic condition.

2) Estimation of benefits

In this step, the results of NJRTM-E network runs with and without capacity improvements obtained in CUBE are then processed in the NJCOST program developed for this project. NJCOST employs ArcGIS in the Visual Basic .NET environment. It calculates costs using the output database files obtained from the CUBE runs. NJCOST can calculate link based or O-D based costs. O-D based cost is calculated using the constrained k-shortest path algorithm that uses C programming language. Link-based costs are calculated for a selected region (e.g. county) or network-wide. In comparing the cost reduction due to the selected projects, link-based cost functionality of NJCOST is employed to calculate total network costs before and after project implementation. The benefits of the project are estimated by the reductions in various cost categories, such as congestion, vehicle operating, accident, air pollution, and noise and maintenance costs at network level. Accordingly, the proposed methodology combines sound economic theory with the output of a highly detailed transportation demand model for estimating the costs and benefits of selected highway projects.

3) Determine the project cost

For the purpose of this study, five past highway improvement projects of New Jersey have selected. Since the construction of all these projects have already finished, total construction costs for all these projects are available. To continue benefit-cost analysis, total construction costs of al projects have selected as the total project cost.

4) Benefit-Cost analysis

This is the last step of the proposed methodology. Total benefits are obtained from NJCOST, using the cost reduction in various cost categories of before and after highway improvement of each project. Total cost is estimated from the total construction cost of each project. Recommended discount rates by the U.S. Office of Management and Budget (USOMB) are used for this analysis. Finally excel sheet is prepared to calculate the benefit-cost ratio of each project.

Figure 5 shows the flowchart of the proposed methodology.

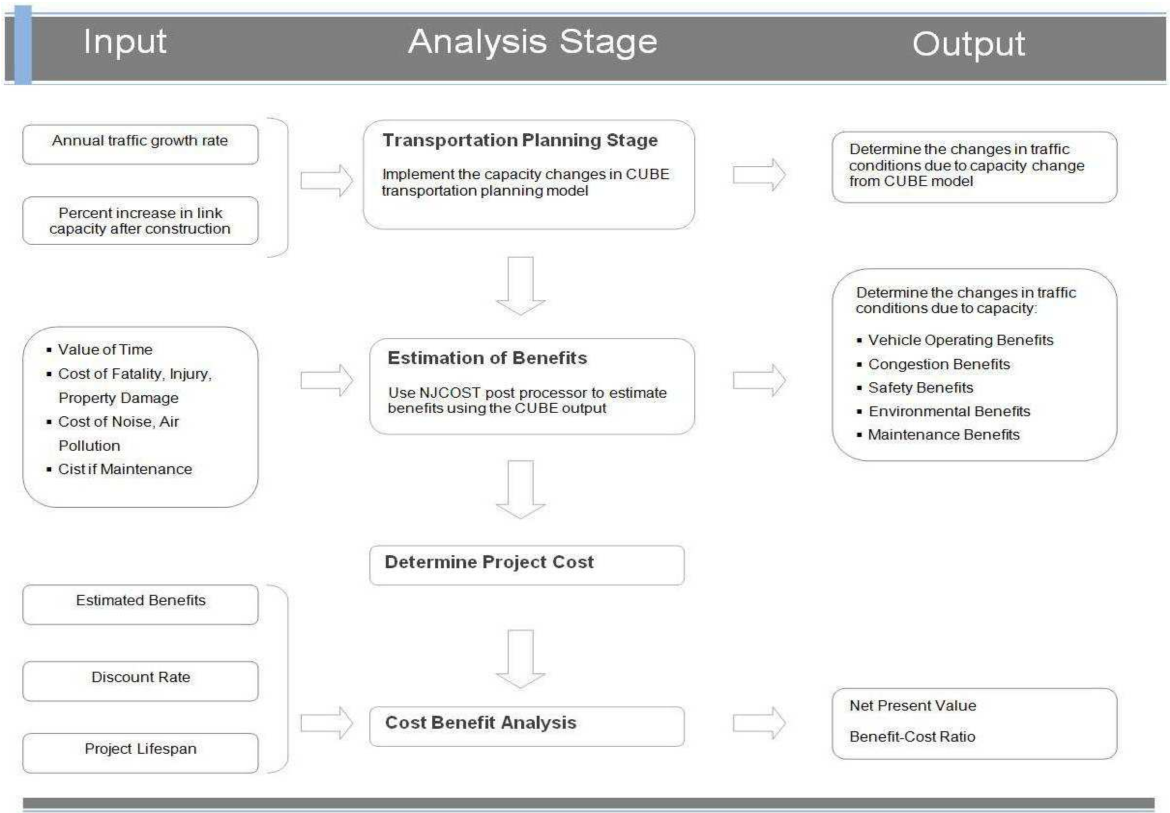

Figure 5: Complete Framework of Proposed Methodology (*70*)

4. Case Studies

Transportation agencies, given finite resources, are routinely faced with the problem of efficiently selecting a subset of transportation projects for implementation from a much larger portfolio of potential projects. One of the major difficulties in project selection is the quantification of the value of time, the value of human life, and the value of various environmental impacts (*71*). With the use of the methodology presented here, this study provides a comprehensive and consistent approach to quantify all transportation costs with respect to different O-D pairs and road sections.

Using the available transportation network of northern NJ, it is possible to estimate the transportation costs for original and modified (i.e., capacity enhanced) network conditions. In this study, the cost reduction impacts of real-world highway capacity investments on several routes are estimated. Five major roadway widening projects, completed between 2004 and 2009 in Northern NJ, were selected for analysis. Table 9 summarizes the details of the selected projects.

Table 9: The Selected Widening Projects in Northern New Jersey (*70*)

Route	Location	Length	Work Type	Cost
Route 17	Bergen County	0.50 miles	Roadway Widening & Bridge Reconstruction	$84.4 million
Route 18	Middlesex County	1.54 miles	Roadway Widening & Extension	$82 million
Route 35	Middlesex Country	1.38 miles	Roadway Widening & Bridge Reconstruction	$129.6 million
Route 1&9	Union County	n/a	Bridge Reconstruction	$72 million
Route 1	Middlesex County	2.92 miles	Roadway Widening & Bridge Reconstruction	$59 million

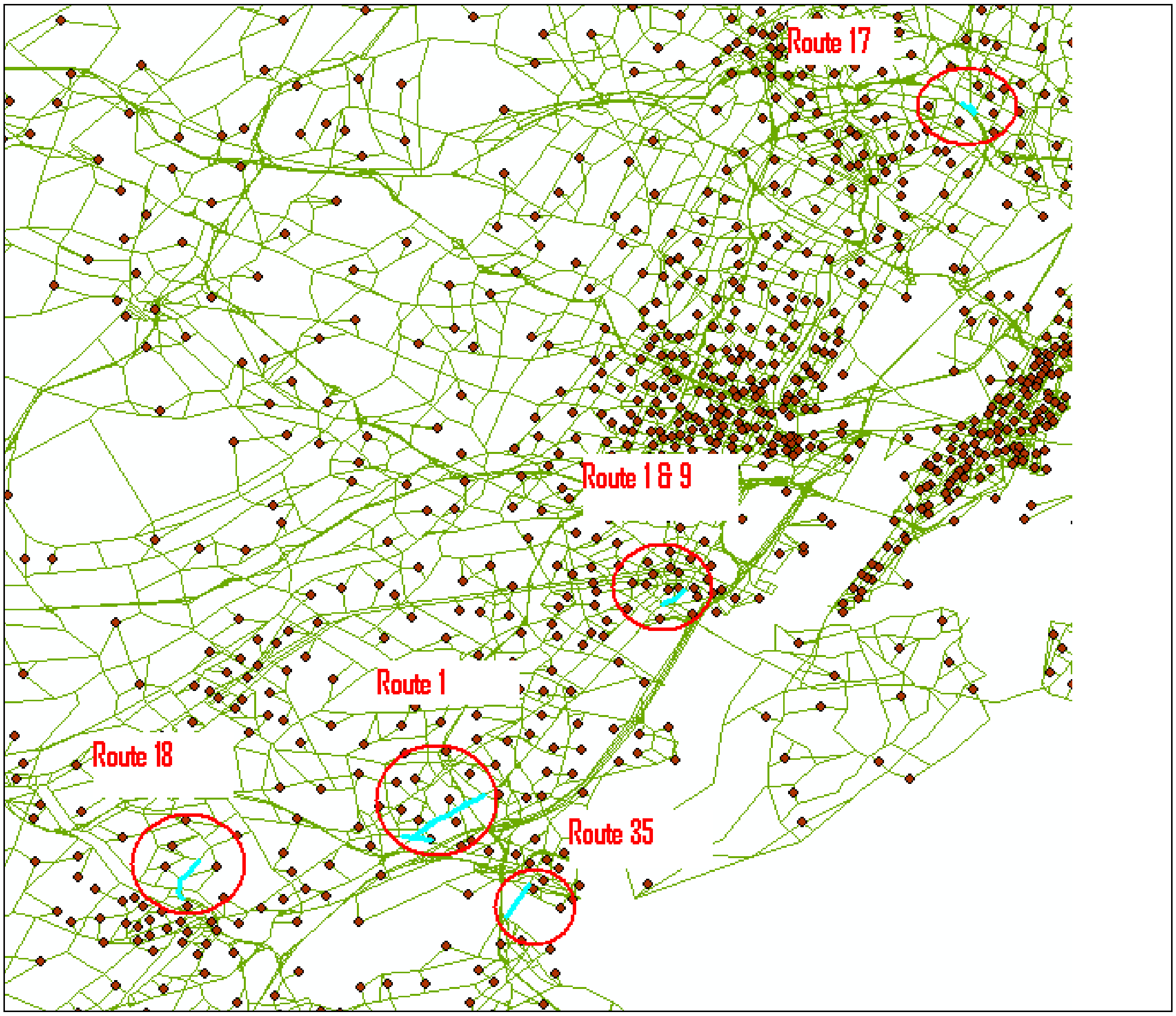

Figure 6: Locations of the Selected Roadway Projects in New Jersey

Figure 6 shows the location of the road sections for which the possible impacts of capacity investment are assessed using the proposed methodology. After increasing the capacity of these road sections traffic is reassigned onto the modified network. The output information obtained from the traffic assignment is used for comparison of before-after costs. The difference is the benefits (i.e., the reduction in costs) attributable to the project. It should be noted that impacts of each capacity investment are investigated separately, i.e. five different modified networks are created for the five different capacity investments. The changes in costs are calculated using the developed GIS tool.

All these are completed projects, so definite cost of construction are known for these projects. Given the cost of the project, and then also given that the benefits are estimated, the net present value of the project can be calculated. A discount rate is used to convert future costs and benefits to present values. Various discount rates recommended by the U.S. Office of Management and Budget (USOBM) (*11*) are used here.

5. Result Analysis

5.1 Application of NJCOST for Highway Improvement Project Evaluation

5.1.1Route 17 Project

This project replaced the existing deficient structure of four-lane Essex Street Bridge with a new, wider structure of six lanes that is compatible with the planned future improvements on route 17. The demolished bridge was 76 years old. The construction of the new bridge and the improvements at the ramps to route 17 were completed in the summer of 2008 (*72*) The allocated funds for this project are shown in Table 10.The total construction cost is calculated for the year 2008 by compounding the costs using 1.6% interest rate.

Table 10: Allocated funds for Route 17 project (*72*)

	2004	2005	2006	2007	2008	Total
Funds Allocated (in millions)	$1.924	$15.38	$13.9	$34.55	$15.6	$83.2

The link corresponding to the Essex Bridge was modified in the NJRTM-E model in accordance with the widening specifications. The O-D matrix for the transportation network from year 2000 is populated for year 2008 using 1% annual traffic growth. The transportation network is run with the original (existing) bridge capacity and with the modified bridge capacity. The NJCOST Software developed by Ozbay *et al.* (*57*) is used to calculate the total cost for the original and the modified network. The results are shown in Table 11.

Table 11:Estimated Total Daily Cost for Original and Modified Networks ($)

Morning Peak (in $)							
	Vehicle Operating	**Congestion**	**Accident**	**Air Pollution**	**Noise**	**Maintenance**	**Total ($)**
Original	12,269,130	39,133,860	3,090,104	1,866,980	42,316.2	688,671.8	57,091,062
Modified	12,201,810	37,791,990	3,054,356	1,865,848	42,233.3	731,113.8	55,687,351.1
Benefit	67,320	1,341,870	35,748	1,132	82.9	-42,442	1,403,710.98
Midday Off-peak (in $)							
Original	13,290,220	14,092,140	4,131,658	2,538,840	65,369.9	1,584,298	35,702,525.9
Modified	13,290,210	14,091,140	4,131,628	2,538,710	65,327.9	1,584,178	35,701,193.9
Benefit	10.0	1,000	30.0	130.0	42.0	120.0	1,332
Afternoon Peak (in $)							
Original	13,737,490	45,214,080	3,422,373	2,054,029	45,853.5	740,909.6	65,214,735.1
Modified	13,705,500	44,701,830	3,407,008	2,052,287	45,835.8	741,083.9	64,653,544.7
Benefit	31,990	512,250	15,365	1,742	17.73	-174.3	561,190.4
Night Off-peak (in $)							
Original	9,350,579	9,712,229	3,744,627	1,805,579	46,189	2,293,476	26,952,679
Modified	9,335,390	9,562,083	3,726,513	1,799,889	45,673.3	2,303,998	26,773,546.3
Benefit	15,189	150,146	18,114	5,690	515.7	-10,522	179,132.7
Total Daily Benefit (in $)							2,145,366.1

It should be noted that the congestion costs shown in Table 11 are estimated based on the lower bound of the VOT assumption as shown in Table 3. Based on the results shown in Table 11, the total daily benefit within the NJRTM-E network due to capacity improvement at the Essex Bridge is estimated as $2.15 million. It should be noted that this value represents an estimated average benefit of the capacity expansion on a given work-day. Annual benefit of this project can be calculated by multiplying the daily benefit by 250 workdays, which equals $536.34 million. The annual benefit does not include benefits that accrue on weekends; therefore it reflects a lower, conservative bound of the benefits of this project.

The annual benefits of this project will not remain constant in the future, given that the bridge life-time is likely to be over 50 years. Due to expected traffic growth in the future, the benefit of this project will diminish over the years. It is assumed that the estimated benefit becomes zero after 25 years due to increased levels of traffic[i]. Based on this assumption the net present value of benefits in 2008 is $5.67 billion, assuming a discount rate of 2.8% for 25 years. The assumption is within 25 years benefits will be linearly reached to zero.

Since the net present value of the benefits outweighs the net present value of construction costs, this project is socially efficient, i.e., it promises to return more to society than it costs. The conservative benefit-cost ratio of this project is 68.08 ($5,665.08m/$83.2m).

5.1.2 Route 18 Extension Project

Route 18 links the New Brunswick area with the north-central New Jersey shore communities. It serves as an east-west route through Middlesex and Monmouth Counties to fill a gap in the existing expressway grid, it provides an alternate route for trucks along the Garden State Parkway Corridor and it also provides an overload route for peak recreational traffic to North Jersey shore resorts.

In 2001, the NJDOT approved a reconstruction as part of its five-year capital program. The four-lane extension follows the route originally proposed in 1962, along the Metlars Lane-Hoes Lane alignment (*72*).

The project was completed in 2004 replacing an existing two-lane roadway with a new four-lane limited access highway. One important objective of the new highway was to eliminate the bottleneck of Metlars Lane and provide the missing link in Route 18 with grade-separated interchanges with River Road, the Rutgers Busch Campus, Metlars lane/Davidson Road and the Rutgers Livingston Campus. The Route 18 extension now feeds into Hoes Lane, a four-lane divided road.

The allocated fund for this project was $75.6 million in 2002. The total construction cost is calculated as $83.2 million in 2008 by compounding the costs using a 1.6% interest rate. The links corresponding to Route 18 in the NJRTM-E model are modified in accordance with the widening specifications. The O-D matrix for the transportation network from year 2000 is populated for year 2008 using 1% annual traffic growth. The transportation network is run with the original (existing) and the expanded roadway capacity. The NJCOST Software developed by Ozbay et al. (*57*) is used to calculate the total cost for the original and the modified network. The results are shown in Table 12.

Table 12:Estimated Total Daily Cost for Original and Modified Networks ($)

Morning Peak (in $)							
	Vehicle Operating	**Congestion**	**Accident**	**Air Pollution**	**Noise**	**Maintenance**	**Total ($)**
Original	12,269,130	39,133,860	3,090,104	1,866,980	42,316.2	688,671.8	57,091,062
Modified	12,181,890	37,494,590	3,045,857	1,864,648	42,199.3	731,733.3	55,360,917.6
Benefit	87,240	1,639,270	44,247	2,332	116.9	-43,061.5	1,730,144.4
Midday Off-peak (in $)							
Original	13,290,220	14,092,140	4,131,657	2,538,840	65,369.9	1,584,298	35,702,524.9
Modified	13,290,190	14,091,990	4,131,689	2,538,826	65,369.4	1,584,272	35,702,336.4
Benefit	30.0	150.0	-32.0	14.0	0.45	26.0	188.4
Afternoon Peak (in $)							
Original	13,737,490	45,214,080	3,422,373	2,054,029	45,853.5	740,909.6	65,214,735
Modified	13,734,350	45,176,190	3,421,061	2,054,931	45,900.4	740,835.8	65,173,268.2
Benefit	3,140	37,890	1,312	-902.0	-46.9	73.8	41,466.9
Night Off-peak (in $)							
Original	9,350,579	9,712,229	3,744,627	1,805,579	46,189	2,293,476	26,952,679
Modified	9,335,382	9,562,021	3,726,508	1,799,894	45,673.7	2,303,998	26,773,476.7
Benefit	15,197	150,208	18,119	5,685	515.4	-10,522	179,202.4
Total Daily Benefit (in $)							1,951,002

VOT assumptions used to estimate congestion costs shown in Table 12 are based on the lower bound of the values shown in Table 3. Based on the results shown in Table 12, the network-wide daily benefit of the Route 18 extension project was estimated at $1.95 million. The annual benefit of this project is calculated by multiplying this times 250 workdays, or $487.75 million. As mentioned earlier, the calculated annual benefit does not include benefits accruing on the weekends, and therefore it is a conservative lower bound of the benefits of this project.

It is assumed that the annual benefits of this project will not remain constant in the future. If we assume conservatively that the life-time of the new roadway is over 25 years, the benefit of this project will diminish over years due to expected traffic growth in the future. It is assumed that the estimated benefit becomes zero after 25 years due to increased levels of traffic. Based on this assumption, the estimated net present value of the benefits is $5.15 billion, assuming a discount rate of 2.8% for 25 years. Since the net present value of the benefits is less than the net present value of construction costs, the roadway expansion was economically efficient based on our assumptions. The benefit cost ratio of this project is 58.95($5,151.85m/$87.4m).

5.1.3 Route 35 Victory Bridge Project

The Victory Bridge in New Jersey carries Route 35 over the Raritan River, connecting Perth Amboy and Sayreville. The new bridge replaced a bridge constructed in 1926. The old bridge carried four 9.5-foot travel lanes with no shoulders. The objective of the new bridge was to boost the regional economy and significantly alleviate congestion and improve safety.

The new bridge consists of twin structures (northbound and southbound) each carrying two 12-foot lanes, a 10-foot bike lane/outside shoulder and a three foot shoulder. The bridge was designed with a 440-foot main span. The project also involved the construction of an access road that is a continuation of a connector roadway from Perth Amboy to the Victory Bridge. The construction was completed in December 2005. The adjusted cost of the project in 2008 dollars was $129.6 million.

The links corresponding to the Victory Bridge in the NJRTM-E model are modified in accordance with the widening specifications. The O-D matrix for the transportation network from year 2000 is populated for year 2008 using 1% annual traffic growth. The transportation network is run with the original (existing) and the expanded roadway capacity. The NJCOST Software developed by Ozbay *et al.* (57) was used to calculate the total cost for the original and the modified network. The results are shown in Table 13.

Table 13:Estimated Total Daily Cost for Original and Modified Networks ($)

Morning Peak (in $)							
	Vehicle Operating	**Congestion**	**Accident**	**Air Pollution**	**Noise**	**Maintenance**	**Total ($)**
Original	12,269,130	39,133,860	3,090,104	1,866,980	42,316.2	688,671.8	57,091,062
Modified	12,202,720	37,776,420	3,055,329	1,865,782	42,235.1	731,017.6	55,673,503.7
Benefit	66,410	1,357,440	34,775	1,198	81.1	-42,345.8	1,417,558.3
Midday Off-peak (in $)							
Original	13,290,220	14,092,140	4,131,657	2,538,840	65,369.9	1,584,298	35,702,524.9
Modified	13,290,120	14,091,140	4,131,627	2,538,840	65,364.9	1,584,298	35,701,389.9
Benefit	100.0	1,000	30.0	0.0	5.0	0.0	1,135
Afternoon Peak (in $)							
Original	13,737,490	45,214,080	3,422,373	2,054,029	45,853.5	740,909.6	65,214,735.1
Modified	13,740,870	45,187,420	3,420,469	2,054,826	45,889.4	740,848.1	65,190,322.5
Benefit	-3,380	26,660	1,904	-797.0	-35.9	61.5	24,412.6
Night Off-peak (in $)							
Original	9,350,579	9,712,229	3,744,627	1,805,579	46,189	2,293,476	26,952,679
Modified	9,335,390	9,562,163	3,726,513	1,799,889	45,673.3	2,303,998	26,773,626.3
Benefit	15,189	150,066	18,114	5,690	515.7	-10,522	179,052.9
Total Daily Benefit (in $)							1,622,158

In Table 13, the estimated congestion costs are based on the lower bound of the VOT ranges as shown in Table3. Based on the results shown in Table 13, the daily benefit of the Victory Bridge reconstruction project was estimated at $1.62 million. The annual benefit of this project can be calculated by multiplying the estimate by 250 workdays, which equals $405.53 million.

As mentioned earlier in the previous analyses, it is assumed that the annual benefits of this project will not remain constant in the future. Although the bridge life-time is usually over 50 years, due to expected traffic growth in the future, the benefit of this project will diminish over years. It is assumed that the estimated benefit becomes zero after 25 years due to increased levels of traffic. Based on this assumption the net present value of benefits in 2008 is $4.28 billion, assuming a discount rate of 2.8%.

Since the net present value of the benefits outweighs the net present value of construction costs, the reconstruction of the Bridge with higher roadway capacity is economically efficient. The benefit cost ratio of this project is 33.05 ($4,283.40m/$129.6m).

5.1.4 Route 1&9 Viaduct Project

The Route 1&9 project involved the staged erection of two bridges (northbound and southbound) to replace the historic Elizabeth Viaduct constructed in 1929 over the Elizabeth River and the downtown marketplace. The old bridge carried two 10-foot travel lanes with no shoulders. Each constructed bridge is 1,870-foot long and 53-foot wide allowing for 3-lanes with one full width and one partial width shoulder for both north and southbound traffic.

Route 1&9 in Elizabeth, NJ serves as one of the region's most critical arteries. The project was undertaken to improve safety and congestion, as well improving the local economy by creating new jobs.

The allocation for this construction project was \$10.5 million, \$36 million and \$25.5 million for the fiscal years 2004, 2005 and 2006, respectively. The compounded cost for the year 2008, assuming a 1.6% interest rate is \$75.3 million.

The links corresponding to Route 1&9 over the Elizabeth River in the NJRTM-E model are modified in accordance with the widening specifications. The O-D matrix for the transportation network from year 2000 is populated for year 2008 using 1% annual traffic growth. The transportation network was run with the original (existing) and the expanded roadway capacity. The NJCOST Software developed by Ozbay *et al*. (*57*) is used to calculate the total cost for the original and the modified network. The results are shown in Table 14.

Table 14: Estimated Total Daily Cost for Original and Modified Networks ($)

Morning Peak (in $)							
	Vehicle Operating	**Congestion**	**Accident**	**Air Pollution**	**Noise**	**Maintenance**	**Total ($)**
Original	12,269,130	39,133,860	3,090,104	1,866,980	42,316.2	688,671.8	57,091,062
Modified	12,192,470	37,574,730	3,050,254	1,865,515	42,223.5	731,008.7	55,456,201.2
Benefit	76,660	1,559,130	39,850	1,465	92.7	-42,336.9	1,634,860.8
Midday Off-peak (in $)							
Original	13,290,220	14,092,140	4,131,657	2,538,840	65,369.86	1,584,298	35,702,524.86
Modified	13,290,210	14,092,130	4,131,658	2,538,837	65,369.91	1,584,270	35,702,474.91
Benefit	10.0	10.0	-1.0	3.0	-0.05	28.0	49.95
Afternoon Peak (in $)							
Original	13,737,490	45,214,080	3,422,373	2,054,029	45,853.5	740,909.6	65,214,735.1
Modified	13,707,520	44,685,900	3,408,057	2,052,300	45,816.5	741,074.0	64,640,667.5
Benefit	29,970	528,180	14,316	1,729	37.0	-164.4	574,067.6
Night Off-peak (in $)							
Original	9,350,579	9,712,229	3,744,627	1,805,579	46,189	2,293,476	26,952,679.0
Modified	9,335,391	9,562,033	3,726,508	1,799,890	45,673.4	2,303,995	26,773,490.4
Benefit	15,188	150,196	18,119	5,689	515.6	-10,519	179,188.6
Total Daily Benefit							2,388,167

The estimated congestion costs in Table 14 are based on the lower bound of the VOT ranges given in Table 3. Using the results given in Table 14, the daily benefit of the viaduct reconstruction project was estimated as $2.38 million. The annual benefit of this project is calculated by multiplying this estimate with 250 workdays, which equals $597.04 million. It is assumed that the estimated benefit will diminish over years due to expected traffic increase. Assuming that the benefit will linearly decrease to zero at the end of 25 years, the net present value of the total benefits is calculated as $6.36 billion in 2008 dollars, assuming a 2.8% discount rate. Therefore, the benefit-cost ratio of this project is 83.75 ($6,306.23m/$75.3m), and the project is economically efficient.

5.1.5 Route 1 Widening Project

The Route 1 widening project will provide three 12-foot lanes with a 3-foot inside shoulder and a 12-foot outside shoulder, or 13-foot auxiliary lane in each direction. Entrance and exit ramps will be added at Pierson Avenue, Grandview Avenue, Parsonage Road and Ford Avenue to aid in the smoothing of traffic. The bridge over Amboy Avenue will be replaced and the exiting ramps will be upgraded. The bridge over the Conrail South Amboy line will be replaced.

The allocated funds for this project were compounded for 2008 by using a 1.6% interest rate, and equal $61.1 million.

The links corresponding to the nearly 3-mile construction on Route 1 in the NJRTM-E model are modified in accordance with the widening specifications. The O-D matrix for the transportation network from year 2000 was populated for year 2008 using 1% annual traffic growth. The transportation network is run with the original (existing) and the expanded roadway capacity. The NJCOST Software developed by Ozbay *et al.* (*57*) is used to calculate the total cost for the original and the modified network. The results are shown in Table 15.

Table 15:Estimated Total Daily Cost for Original and Modified Networks ($)

Morning Peak (in $)							
	Vehicle Operating	**Congestion**	**Accident**	**Air Pollution**	**Noise**	**Maintenance**	**Total ($)**
Original	12,269,130	39,133,860	3,090,104	1,866,980	42,316.23	688,671.8	57,091,062.03
Modified	12,192,460	37,634,050	3,048,894	1,865,091	42,197.50	731,246.3	55,513,938.80
Benefit	76,670	1,499,810	41,210	1,889	118.73	-42,574.5	1,577,123.23
Midday Off-peak (in $)							
Original	13,290,220	14,092,140	4,131,657	2,538,840	65,369.86	1,584,298	35,702,524.86
Modified	13,290,090	14,092,020	4,131,995	2,538,691	65,363.08	1,584,134	35,702,293.08
Benefit	130.0	120.0	-338.0	149.0	6.78	164.0	231.78
Afternoon Peak (in $)							
Original	13,737,490	45,214,080	3,422,373	2,054,029	45,853.54	740,909.6	65,214,735.14
Modified	13,737,660	45,209,970	3,419,410	2,054,795	45,891.86	740,106.3	65,207,833.16
Benefit	-170.0	4,110	2,963	-766.0	-38.32	803.3	6,901.98
Night Off-peak (in $)							
Original	9,350,579	9,712,229	3,744,627	1,805,579	46,189.01	2,293,476	26,952,679.01
Modified	9,335,402	9,561,970	3,726,421	1,799,884	45,673.55	2,303,973	26,773,323.55
Benefit	15,177	150,259	18,206	5,695	515.46	-10,497	179,355.46
Total Daily Benefit							1,763,612.45

As mentioned earlier, the congestion costs given in Table 15 are estimated based on the lower bound of the VOT assumption in Table 3. Daily benefit of the Route 1 widening project was estimated at $1.76 million using the results shown in Table 15. The annual benefits of this project can be calculated by multiplying this estimate by 250 workdays, and equal $440.90 million. The assumption is that the estimated benefit will not remain the same over years due to expected traffic increase and that the benefit will linearly decrease to zero at the end of 25 years, the net present value of the total benefits is calculated as $4.65 billion in 2008 dollars, assuming a 2.8% discount rate. Therefore, the benefit cost ratio of this project is 76.21 ($4,657.0m/$61.1m), and the project is economically efficient based on the assumptions.

5.1.6 Sensitivity Analysis

In this section, the variation in the benefit-cost ratio of the selected project is investigated with respect to the assumptions in calculating benefits. The variables that are subject to the sensitivity analysis are the value-of-time (VOT) and the level of capacity increase. The VOT ranges for passenger cars and trucks during peak and off-peak hours are shown in Table 3. The benefit-cost ratios for each project presented in the previous section were based on the low VOT range.

The increase in capacity due to each project was reflected in the NJRTM-E CUBE model by multiplying the base capacity by a factor that is estimated based on the project specifications such as the increase in number of lanes and addition of shoulders. The benefit cost ratios presented in the previous section were based on these assumptions of capacity increase (low capacity increase results). For sensitivity analysis, the variation in benefit cost ratios is investigated by assuming a higher increase in capacity than initially assumed capacity. Therefore, the factors that were used to increase capacity for each project were doubled in the CUBE model, and new results were obtained accordingly (high capacity). For example, if the base capacity is 3,000 veh/hr, and initial assumption of the new capacity is 3,500 veh/hr, then the upper bound of capacity is assumed as 4,000 veh/hr in the sensitivity analysis.

The benefit-cost ratio of each project based on various ranges of VOT and the level of capacity are presented in Table 16. It should be noted that the benefits are converted to 2008 dollars using the discount rates shown in Table 1.

Table 16: Benefit–Cost ratios of Sensitivity Analyses

	High Capacity		**Low Capacity**	
	Low VOT	*High VOT*	*Low VOT*	*High VOT*
Route 17	69.40	104.37	68.08	83.20
Route 18	60.41	91.16	58.94	88.95
Route 35	34.41	55.10	33.05	52.86
Route 1&9	83.88	125.98	83.75	125.77
Route 1	92.41	106.74	76.21	93.72

It can be seen from the results presented in the previous section that the majority of the benefits are due to reduction in congestion costs. Therefore, the VOT assumption significantly affects the benefit-cost ratios shown in Table 16.

5.2 Network Wide Impact of Highway Improvement Projects

Usually existing road improvements are made based on the local area in which the road itself is located. However, sometimes these improvements can affect the surrounding network due to its connection to other roads. Increased capacity of certain route can create induced traffic demand and consequently the traffic pattern of connected routes can be changed. This section will observe how the highway capacity improvement of one location affects the complete transportation network. To understand the network wide impact of local improvements, benefit-cost analysis is conducted at different geographical level for the selected highway improvement projects of this study. Change in benefit-cost ratio along with the different geographic level has captured the network-wide impact of the case studies.

To analyze the network wide impact, three case studies are selected from the previous section and name of the projects are; (1) Route 18 improvement, (2) Route 35 Improvement and (3) Route 17 Improvement project. All these projects were completed between 2004 and 2009 in Northern NJ. Basically the proposed methodological framework of highway improvement evaluation is repeated in this section. The NJRTM-E network is run with and without capacity improvements, and the network traffic flows are obtained from CUBE. After increasing the capacity of these road sections, using the same origin-destination (O-D) demand matrices, traffic is reassigned onto the modified network, and the output information obtained from the traffic assignment is used for comparison of before-after costs. Impacts of each capacity investment are investigated separately, i.e. three different modified networks are created for three different capacity investments.

Using the before and after network results, the benefits are estimated through reduction in various cost categories, such as congestion, vehicle operating, accident, air pollution, noise and maintenance costs using the developed GIS tool by Ozbay et al. (*57)*. Cost functions of this GIS-based tool to calculate the cost in different categories are presented Table 8. This GIS based tool has the option of performing the analysis by TAZ selection, county-to-county selection, intra-county selection and entire network selection. In this study, TAZ selection option and entire network selection are used. Using TAZs selection option, multiple O-D pairs are selected at different distances from the improved route section. TAZs are selected at first at 1 mile radius and then at 5 mile radius of the improvement site. The TAZs selection option analyzes the local impact of the improvements. Then the entire network selection option is used to analyze the network-wide impact of improvement projects. Finally average daily benefits of each project are compared to evaluate the local impact and network wide impact. In following paragraphs, result analysis of three case studies is presented.

5.2.1 Case Study 1: Route 18 Extension Project

According to the description of Route 18 improvement project, capacities of five links are changed in CUBE NJRTM-E model. NJRTM-E network is run with and without the capacity improvements and the output networks are compared to find the change in total volume, speed, time and volume-capacity (V/C) ratio.

Figure 7 identifies the change in total volume (in percentage) for the entire network caused after increasing the capacity of Route 18. The modified network shows that total volumes of the five improved links have increased. Total volumes increment of these links has varied from 1.8% to 7%. However, volume change for the entire network does not show any exact pattern. Volume has increased in some connected links but has reduced in others. In Figure 7, color coding in red identifies links where volume change is at its highest; brown identifies moderate change; followed by green identifying least amount of change.

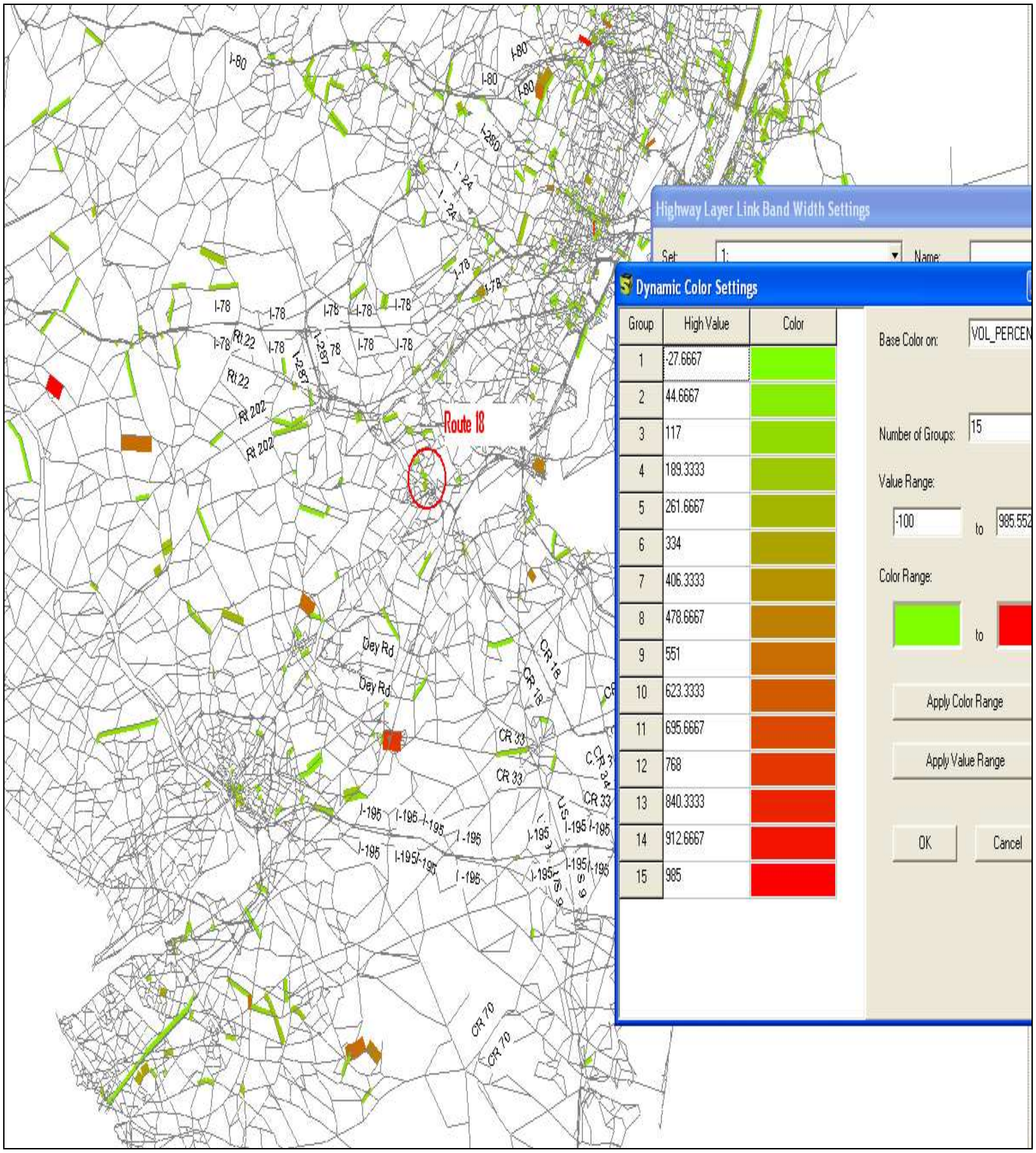

Figure 7: Change in Total Volume Percentage for the Entire Network after the construction of Route 18 Capacity Improvement Project

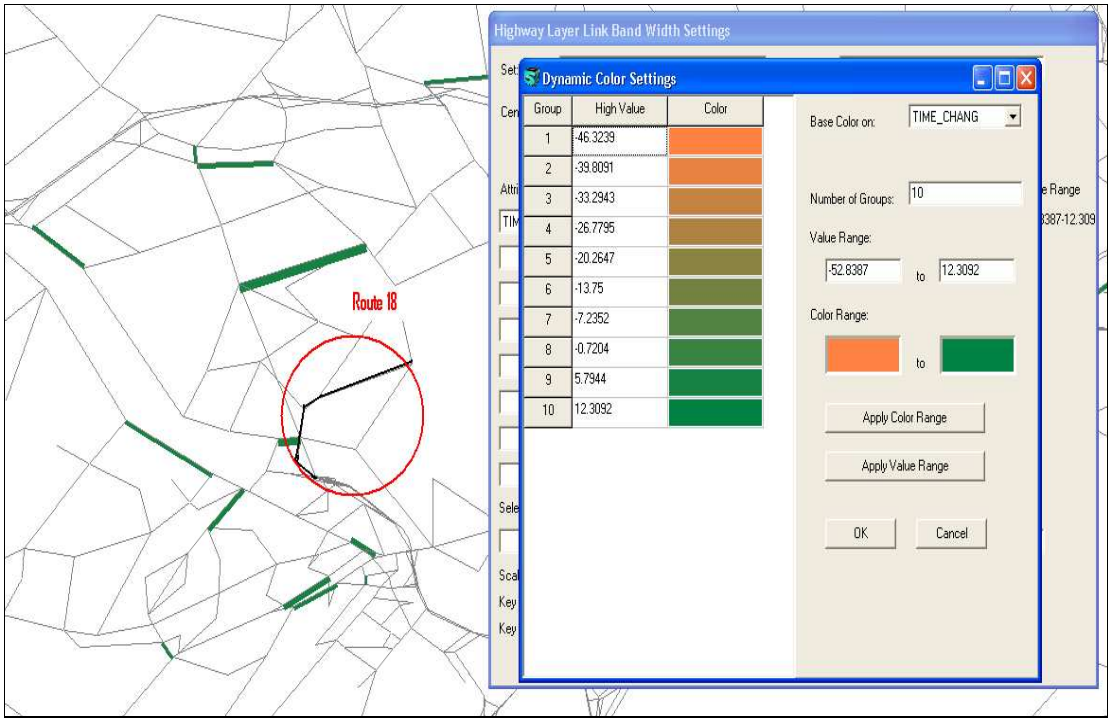

Figure 8: Change in Congested Travel Time for the Entire Network after the construction of Route 18 Capacity Improvement Project

In Figure 8 the change in travel times for the entire network after Route 18 improvement is shown. The maximum travel time reduction is 52 minutes and maximum travel time increase is 12 minutes. Travel times of five improved links of Route 18 have slightly reduced after improvement.

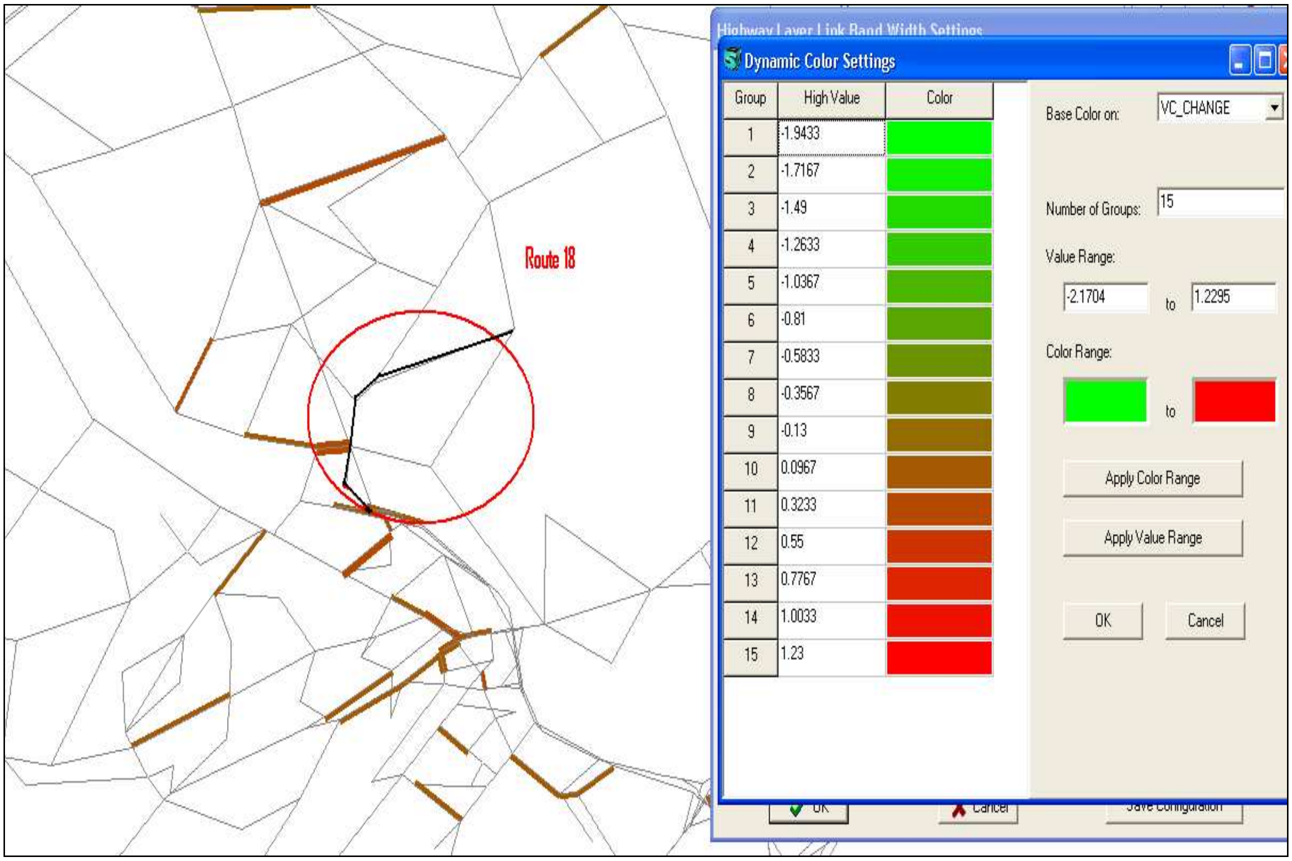

Figure 9: Change in Volume-Capacity Ratio for the Entire Network after the construction of Route 18 Capacity Improvement Project

Figure 9 shows the change in volume-capacity ratio after the improvement of Route 18. The volume-capacity ratio change has varied from - 2.17 to 1.23. Here, negative change indicates the reduction of volume-capacity ratio and positive sign indicates increase of the volume-capacity ratio.

Table 17 summarizes the change in characteristics of improved links of Route 18. Capacity increment has reduced the volume-capacity ratio of improved links. Travel time of these links have reduced slightly. However total volume of these links have increased. Speed values for these links have remained unchanged.

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Table 17: Change in characteristics of improved links

Link Number	O-D Pair	Change in VC Ratio	Change in Travel Time (min)	Change in Total Volume (%)	Change in Speed (mph)
1	27666-5090	-0.5856	-0.208	7.05	0
2	5090-5091	-0.6586	-0.1693	7.05	0
3	5091-5089	-0.1249	-0.0023	3.03	0
4	5089-5093	-0.0059	-0.0059	1.81	0
5	5093-917	-0.0003	0	-2.93	0

Table 18 shows the change in average daily benefits for Route 18 improvement at different geographic levels. This result shows positive system-wide impacts along with the localized benefits. Origin-destination trip analysis within smaller radius of improved road section, interprets localized benefits and the entire network analysis result represents network-wide impact of highway capacity improvement projects. The benefit has increased gradually with the increasing radius of the area analyzed.

Table 18: Average Estimated daily benefits at different geographic level

Analysis Process	Daily Benefits for Route 18 ($)
Manually selected TAZs within 1 mile radius of improved Road section	$4,368.66
Manually selected TAZs within 5 mile radius of improved Road section	$10,794.14
Manually selected TAZs within 15 mile radius of improved Road section	$43,176.56
Entire Network Analysis	$1,951,002.12

5.2.2 Case Study 2*: *Route 35 Victory Bridge Project

Similar analysis procedure of Case Study 1 is applied to Case Study 2. The change in characteristics of improved links of Route 35 are summarized in Table 19. Capacity increment has reduced the volume-capacity ratio of improved link. Congsted travel time of the link has not changed at all but total volume on the link has increased by 7.32%. Speed value for the link has remained same as before.

Table 19: Change in characteristics of the improved links

Link Number	O-D Pair	Change in VC Ratio	Change in Travel Time (min)	Change in Total Volume (%)	Change in Speed (mph)
1	5241-27430	-0.0253	0	7.32	0

Table 20: Average daily benefits at different geographic area

Analysis Process	Daily Benefits for Route 35 ($)
Manually selected TAZs within 1 mile radius of improved Road section	$9,570.67
Manually selected TAZs within 5 mile radius of improved Road section	$47,195.86
Manually selected TAZs within 15 mile radius of improved Road section	$57,424.02
Entire Network Analysis	$1,622,158

Table 20 shows the change in average daily benefits for Route 35 improvement at different geographic level. Origin-destination trip analysis within smaller radius around improved road section represents localized benefits and the entire network analysis result represents network-wide impact of highway capacity improvement projects. This project shows benefits for small network and also for the entire network.

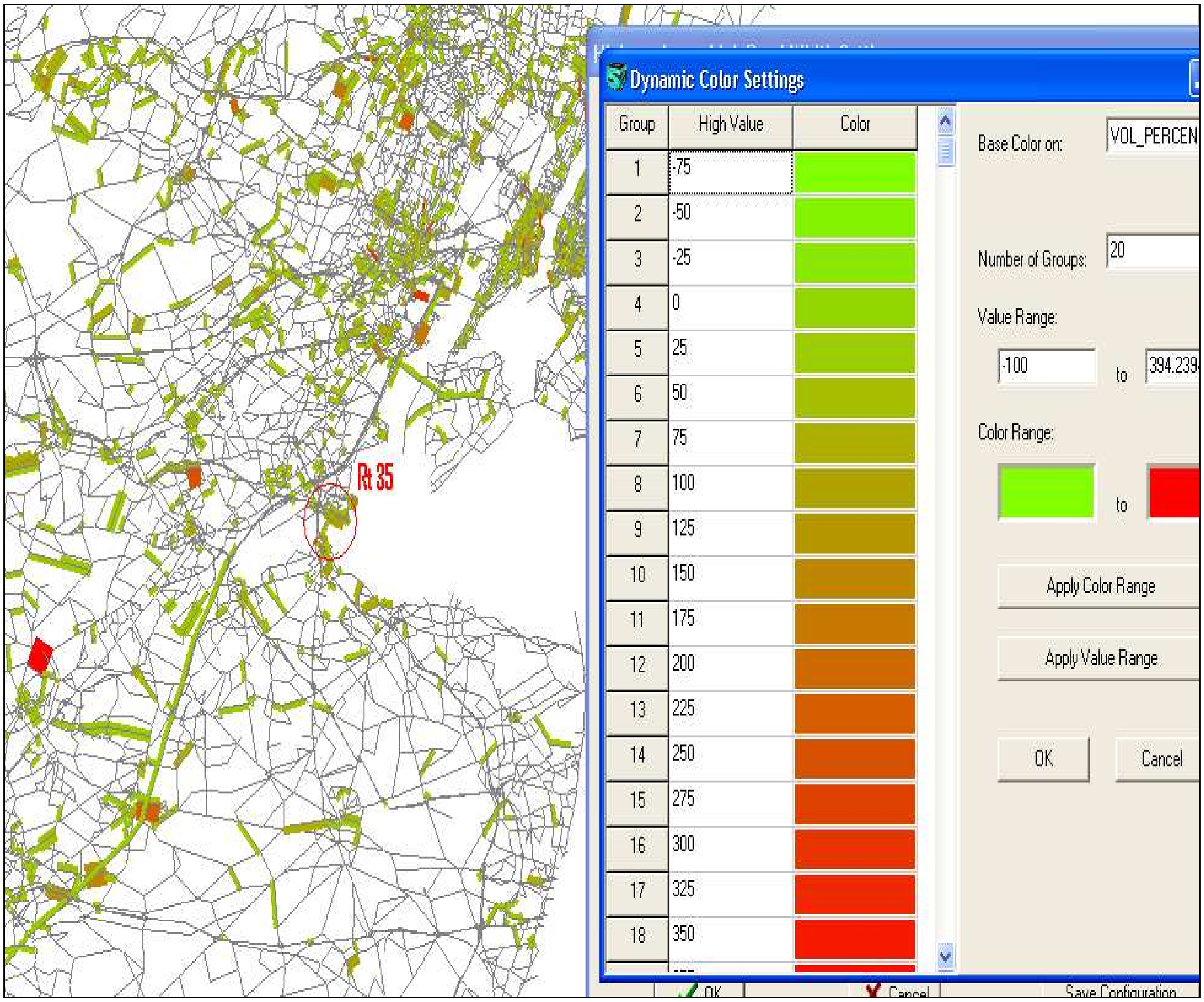

Figure 10: Change in total volume percentage for the Entire Network after the construction of Route 35 Capacity Improvement Project

Figure 10 shows the change in total volume (in percentage) for the entire network caused after capacity improvement project of Route 35. The total volume of the link has increased to 7.32% after the improvement. However, volume change for the entire network does not show any pattern. Volume has increased in some connected links but has reduced in others. In Figure 10, color coding in red identifies links where volume change is at its highest, brown identifies moderate change followed by green identifying least amount of change.

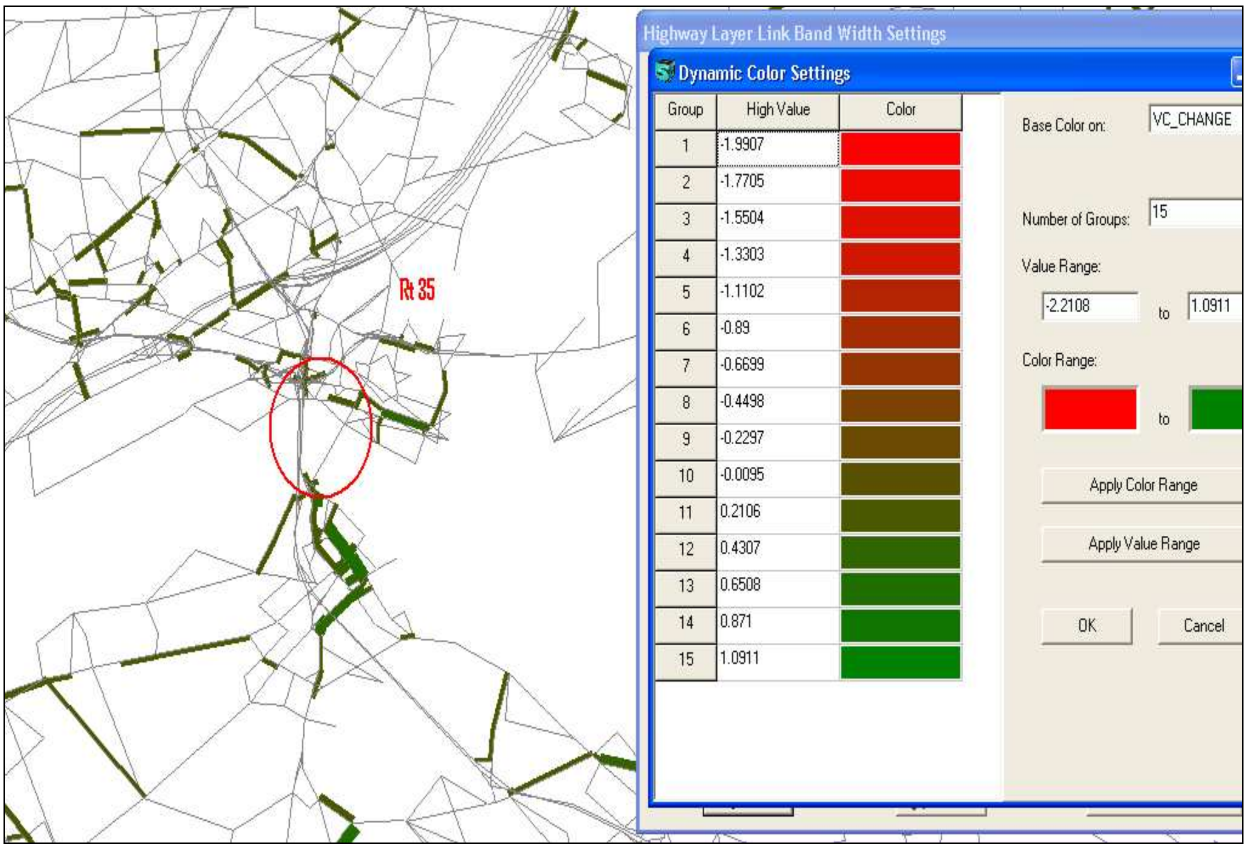

Figure 11: Change in volume-capacity ratio for the Entire Network after the construction of Route 35 Capacity Improvement Project

Figure 11 shows the change in volume-capacity ratio after the improvement of Route 35. The volume-capacity ratio change has found between -2.21 to +0.0283. Here, negative change indicates the reduction of volume-capacity ratio and positive sign indicates increase of volume-capacity ratio.

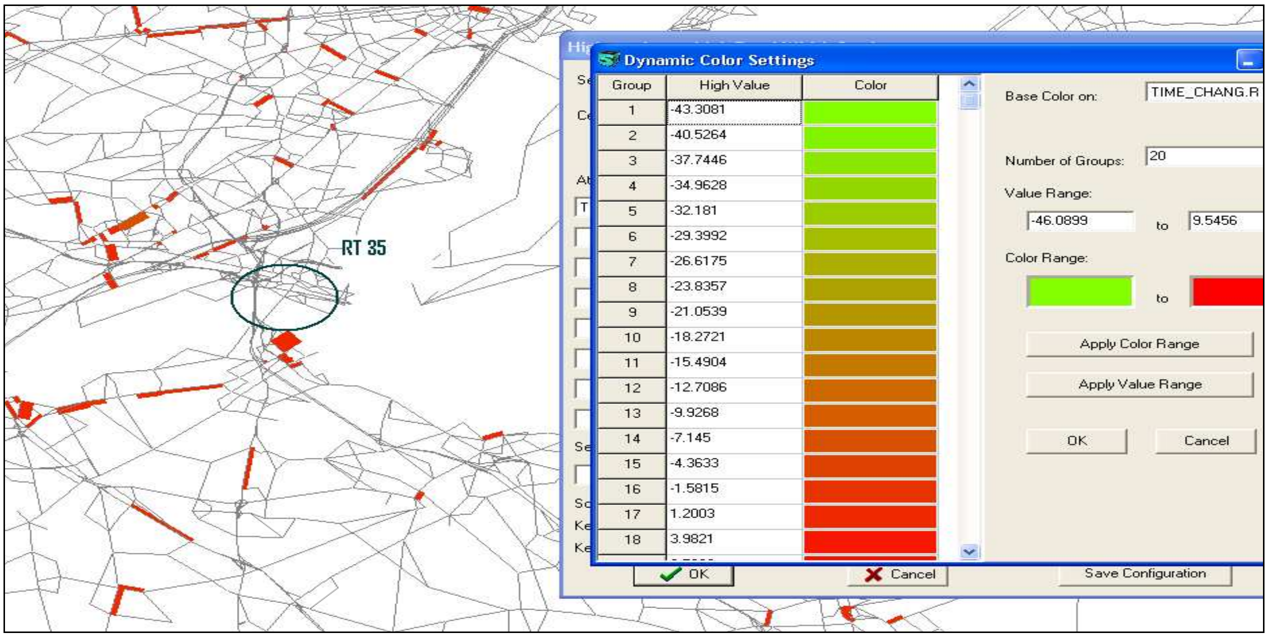

Figure 12: Change in travel time for the entire network after the construction of Route 35 Capacity Improvement Project

Figure 12 shows the change in travel time for complete network. Travel time has been changed from -46.08 minutes to +9.55 minutes for the entire network. Here, negative change indicates the reduction of travel time and positive sign indicates increase of travel time. Travel time for the modified link has remained unchanged.

5.2.3 Case Study 3: Route 17 Project

Similar analysis procedure of Case Study 1 is applied to Case Study 3. Table 21 summarizes the change in characteristics of improved links of Route 17 .Capacity increment has reduced the volume-capacity ratio of the improved links. Congsted travel time of the link has remained almost same. Total volumes of three links have reduced but volume has increased in two links. Speed values for these links have not chnaged .

Table 21: Change in characteristics of the improved links

Link Number	O-D Pair	Change in VC Ratio	Change in Travel Time (min)	Change in Total Volume (%)	Change in Speed (mph)
1	8933-37534	-0.0832	0	-5.07	0
2	37534-39148	-0.2287	-0.0002	-12.32	0
3	39148-39153	-0.1393	0	-0.65	0
4	39153-37535	-0.1382	0	+ 0.138	0
5	37535-39151	-0.1382	0	+ 0.138	0

Table 22: Average daily benefits at different geographic area

Analysis Process	Daily Benefits for Route 17 ($)
Manually selected TAZs within 1 mile radius of improved Road section	$789.25
Manually selected TAZs within 5 mile radius of improved Road section	$29,149.54
Manually selected TAZs within 15 mile radius of improved Road section	$43,724.31
Entire Network Analysis	$2,145,366.1

Table 22 shows the change in average daily benefits for Route 17 improvement at different geographic levels. Origin-destination trip analysis within smaller radius of improved road section, interprets localized benefits and the entire network analysis result represent network wide impact of highway capacity improvement projects. This project shows comparatively higher benefits for the entire network compare to the smaller network.

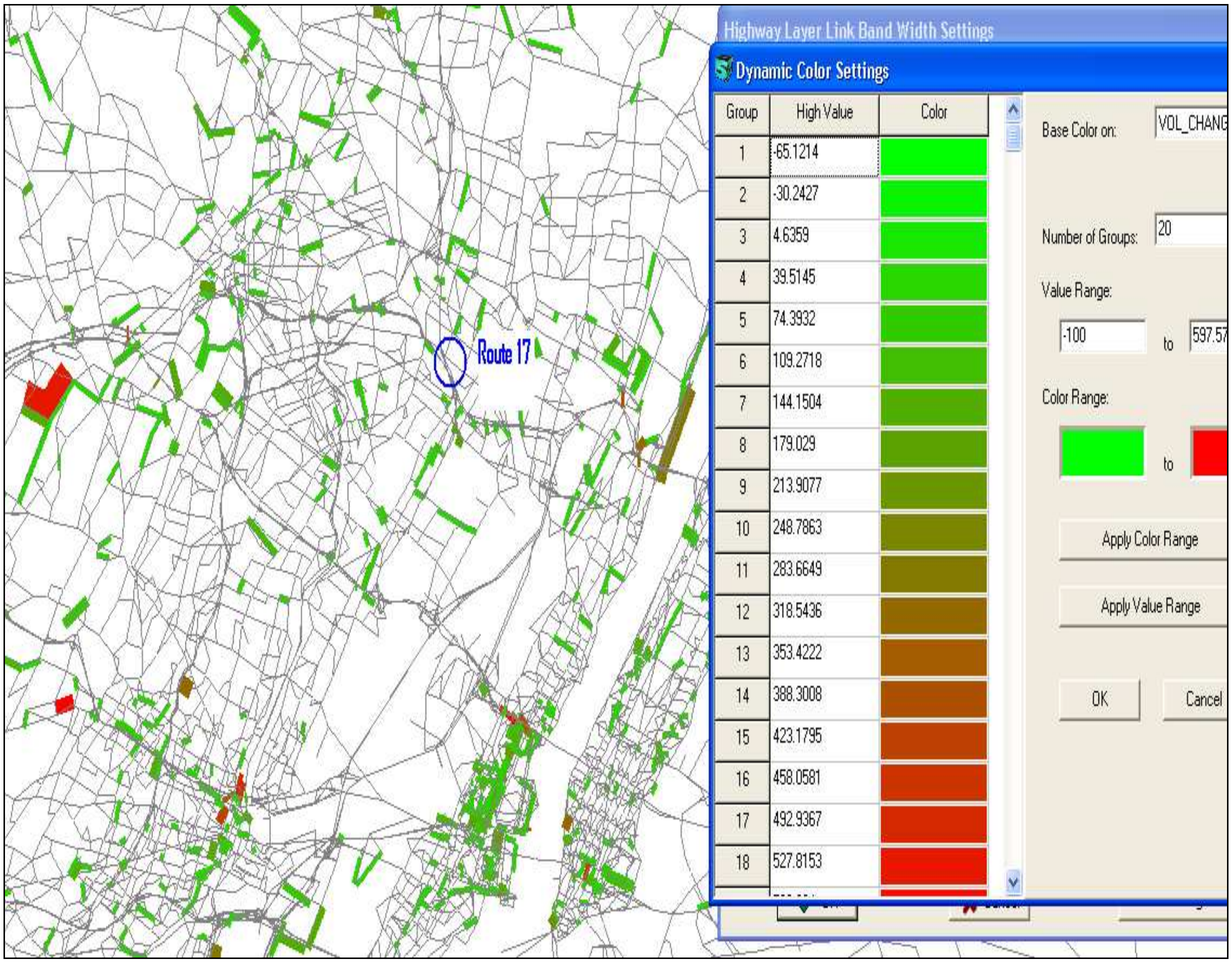

Figure 13: Change in total volume percentage for the Entire Network after the construction of Route 17 Capacity Improvement Project

Figure 13 shows the change in total volume (in percentage) for the entire network caused after improving Route 17. Total volume has reduced in three links but has increased in two links. However, volume change for the entire network does not show any pattern. Volume has increased in some connected links but has reduced in others. In

Figure13, color coding in red identifies links where volume change is at its highest, brown identifies moderate change followed by green identifying least amount of change.

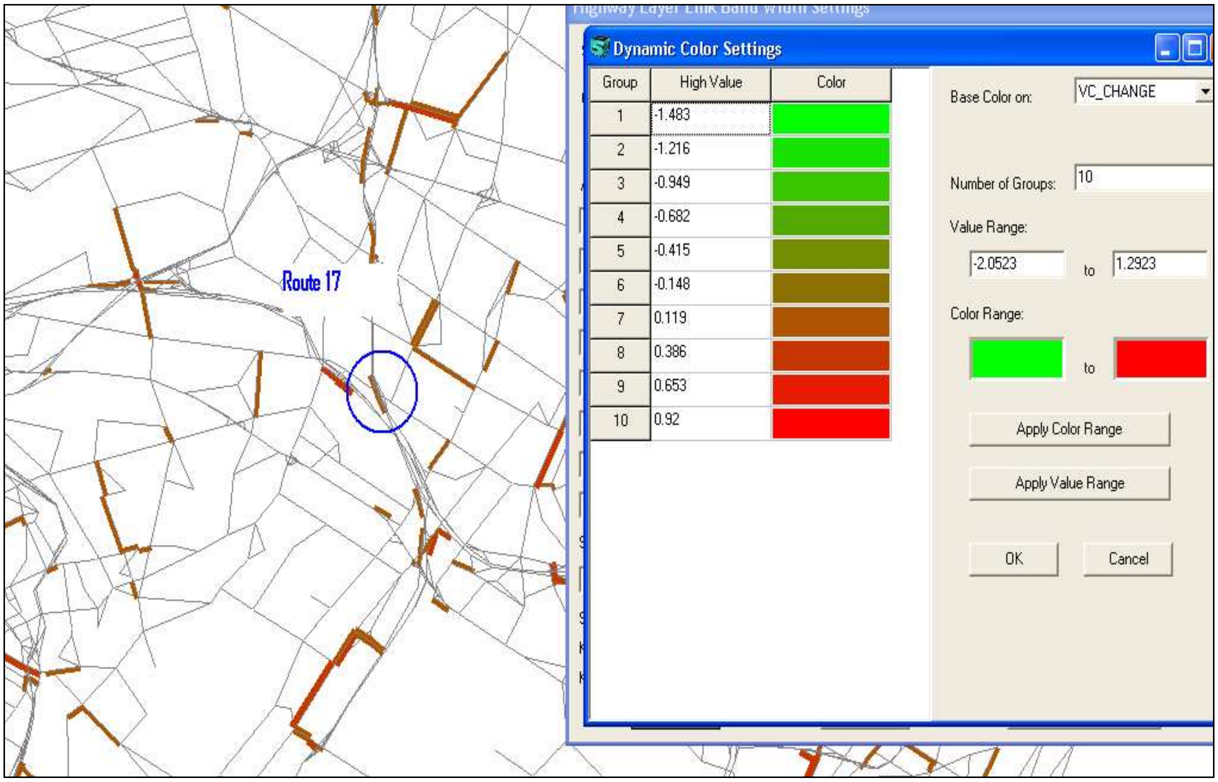

Figure 14:Change in volume-capacity ratio for the Entire Network after Route 17 Capacity Improvement Project

Figure 14 shows the change in volume-capacity ratio after the improvement of Route 17. Volume-capacity ratio has been changed from -1.75 to +0.92. Here, negative change indicates the reduction of volume-capacity ratio and positive sign indicates increase of volume-capacity ratio.

5.2.4 Analysis of estimated Network-Wide Benefits

While selecting the required highway improvement project, it is important to consider the network wide impact along with the localized impact. Local highway improvement project can show high regional benefits compared to the network-wide benefits. Basically highway improvements projects do not always eliminate remove the congestion problem completely. These projects might just shift the traffic demand to some other location or try to attract more traffic to the same route. It is very possible that induced demand from increased capacity could have impacts on the connected routes. Reduced congestion of one route may increase congestion costs at other places. Evaluation of investment projects on the basis of total network benefit conducts can improve the reliability of this type of analysis analysis. To illustrate this hypothesis cost-benefit analysis is conducted for a small area around the improved road section and also for the entire network. Cost-benefit analysis for the entire network represents the complete impact of a given highway investment project. The same analysis for a smaller area represents the localized benefits.

According to the analysis, estimated daily benefits of all projects studied in this thesis have increased with the increased boundary of the projects. After the estimation of daily average benefits for a facility and the complete network analysis, benefit-cost ratios are calculated and presented in Table 22. Comparing the B/C ratios, it can be said for localized benefits for the Route 18 project is higher than other projects. However, considering the entire network effect, Route 17 project returns the most benefits.

Table 23: Benefit-Cost ratios (B/C) for facility-base and network-wide analysis

Project Name	Facility-Based B/C Ratio	Entire Network-Based B/C Ratio
Route 18	1.39	61.92
Route 35	1.08	33.05
Route 17	1.17	68.23

It is expected that after the network improvements, volume/capacity (V/C) ratios of the specific links will be reduced. In three case studies, overall V/C ratio has reduced to some extent in most of the regions but at some places it has increased. Reduction of V/C ratios indicates the reduction of congested travel time on the routes. Overall through these improvements, total system travel time has reduced. Without considering these three highway improvements total travel time for the entire network was 5.53×10^{12} hours After improving Route 35, Route 17 and Route 18, it becomes respectively 5.49×10^{12} hours, 5.48×10^{12} hours and 5.46×10^{12} hours.

5.3 Impact of Highway Improvement Projects on the Change in Accessibility

Accessibility measures reflect the level of service provided by transportation systems to various locations. In this section, the objective of analysis is to find the change in accessibility caused by highway improvement projects. To calculate the accessibility change following case studies are selected from the previous section (1) Route 18 Improvement Project, (2) Route 35 Improvement Project and (3) Route 17 Improvement Project.

All accessibility measures have two components. First one in the attractiveness component and the second one is the impedance component. The attractiveness component is usually measured as the number of opportunities at destinations. This can be number of jobs, population, or any other attraction components which cause people to make trips from origin to destination zones. However, the impedance component decreases the probability of being attracted to destinations. In general, travel cost, distance or travel time between origin and destination zone is used as impedance component of accessibility measure.

In this section, total number of employees at each Traffic Analysis Zone (TAZ) is selected as the attraction factor. Socioeconomic data for each TAZ of NJRTM-E Travel Demand Model are available at NJTPA website (*68*). Basically GIS file of Traffic Analysis Zones (TAZs) along with database files of socioeconomic data by TAZ is joined to the TAZ GIS file. After integrating the two GIS files together in NJCOST, all socioeconomic data for any TAZ in the network become available. Among different socioeconomic data, number of total jobs is selected as the attraction factor in this study. In socioeconomic database projected employment data are given for five different years. Since the three case studies were completed between 2004 and 2009 in Northern NJ, projected numbers of jobs for year 2010 are used.

In this study, congested travel cost between each origin and destination zone is used as impedance factor for the accessibility calculations. To estimate the impedance factor, output results of NJRTM-E network are used. Three different modified networks are created for three different capacity investments. The NJRTM-E network is run with and without capacity improvement projects and the output results are used in ASSIST-

ME/NJCOST to get the congested travel cost as a result of these improvement projects. Two different analysis techniques are used here to get the cost. One is intra-county (within a single county analysis) and the other one is inter-county (from one county to another county analysis). Intra-county analysis is conducted within the county where the improvement took place and inter-county analysis is computed between the improved county (where improvement took place) and the neighboring county. In intra-county analysis, the nearest TAZ of the improved location is selected as origin and 100 TAZs within the county are selected as destinations in NJCOST. The result of this analysis gives total costs and travel time for 100 different origin-destination pairs. The same procedure is applied for both original (without any highway improvement) and modified network (after highway improvement). Finally the common origin-destination (O-D) pairs of base and modified networks are identified to compare the travel time..

The same analysis procedure is applied for inter-county analysis. In intra-county analysis destination points or TAZs are selected within the county where the improvement took place. However in inter-county analysis, destination pints or TAZs are selected from neighboring counties of the improved location.

After identifying the components of accessibility index which are respectively number of employment and travel time, a simplified form of Hansen's Accessibility Index is used to calculate the accessibility. The accessibility index formula is presented in Eq. (7)

$$A_{ij} = \sum_{i=1}^{i=m} \frac{E_j}{c_{ij}^{\beta}} \qquad (7)$$

Where, i = origin TAZ from where trip starts; j = destination TAZ where trip ends; m = number of origin-destination pair; E_j = Total number of employment at destination TAZ; c_{ij} = travel time between origin and destination TAZ; β= exponent (assumed to be 2 as a default value)

In following sections, accessibility results for three different projects are presented.

5.3.1 Case Study 1: Route 18 Extension Project

Route 18 improvement project took place in Middlesex County, NJ. This construction was over 1.54 miles length of Route 18. Two neighboring counties of the improve road section of Route 18 are respectively, Somerset County and Union County. Figure 15 shows the improved road section.

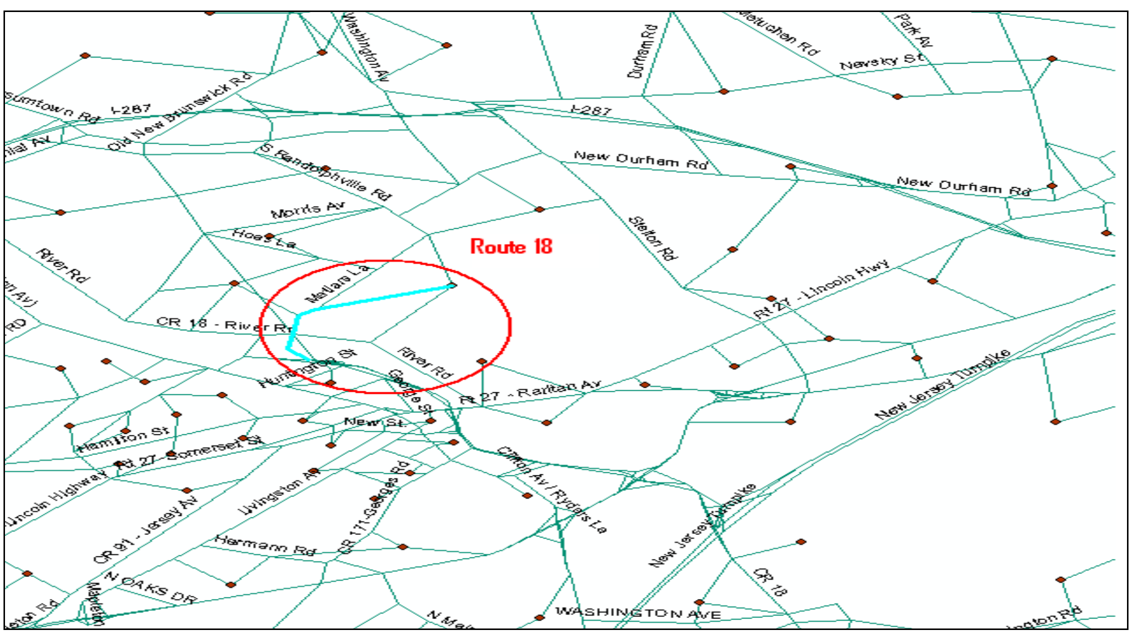

Figure 15: Route 18 improvement location

According to the procedure of accessibility calculation adopted in this study, the nearest TAZ of the improved road section is selected as origin and another 100 TAZs are selected as destinations within the Middlesex County in ASSIST-ME/NJCOST. This manual selection gives total 100 O-D pair trip analysis within Middlesex County. Travel times of the selected O-D pairs are compared. In Figure16 origin node in this analysis is highlighted in red color.

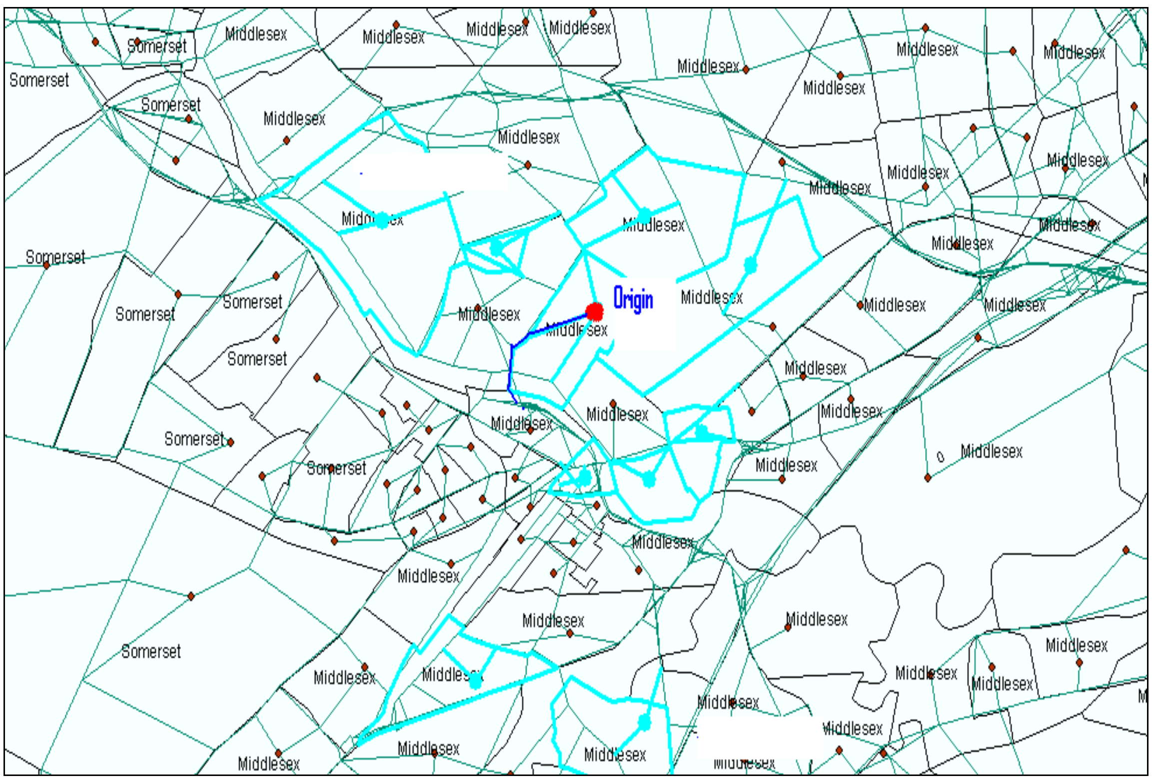

Figure 16: Selected origins and destinations in Middlesex County

Table 24. Route 18 Accessibility of the Base Network vs. the Modified Network within Middlesex County

O_D pair of Base & Modified Network	Travel Time (minute) of the Base Network	Travel Time (min) of the Modified Network	Number of Employment in Destination zone	Accessibility of the Base Network (No of Jobs/min)	Accessibility of the Modified Network (No of Jobs/min)
917-1010	962.49	586.46	3364	0.004	0.010
917-930	300.32	81.58	1055	0.012	0.159
917-942	669.13	346.55	6972	0.016	0.058
917-922	466.29	104.08	7914	0.036	0.731
917-918	39.7	37.75	3026	1.920	2.123
917-931	89.85	81.58	285	0.035	0.043
917-920	216.3	55.11	6	0.000	0.002
917-1002	441.19	275.3	8034	0.041	0.106
917-1017	1,079.54	771.05	1705	0.001	0.003
Total Accessibility				2.065	3.23

Table 24 shows that, total accessibility of base network is 2.065 and after the improvement it becomes 3.23. After the improvement of Route 18 accessibility has increased by 56.42%. If travel time is assumed to be reduced by 10% after improvement, accessibility index value becomes 2.55 and the total accessibility would have increased by 23.48%. In this analysis accessibility has increased by 56.42% which is greater than 23.48%. Thus it can be concluded that Route 18 improvement has improved the accessibility of that region.

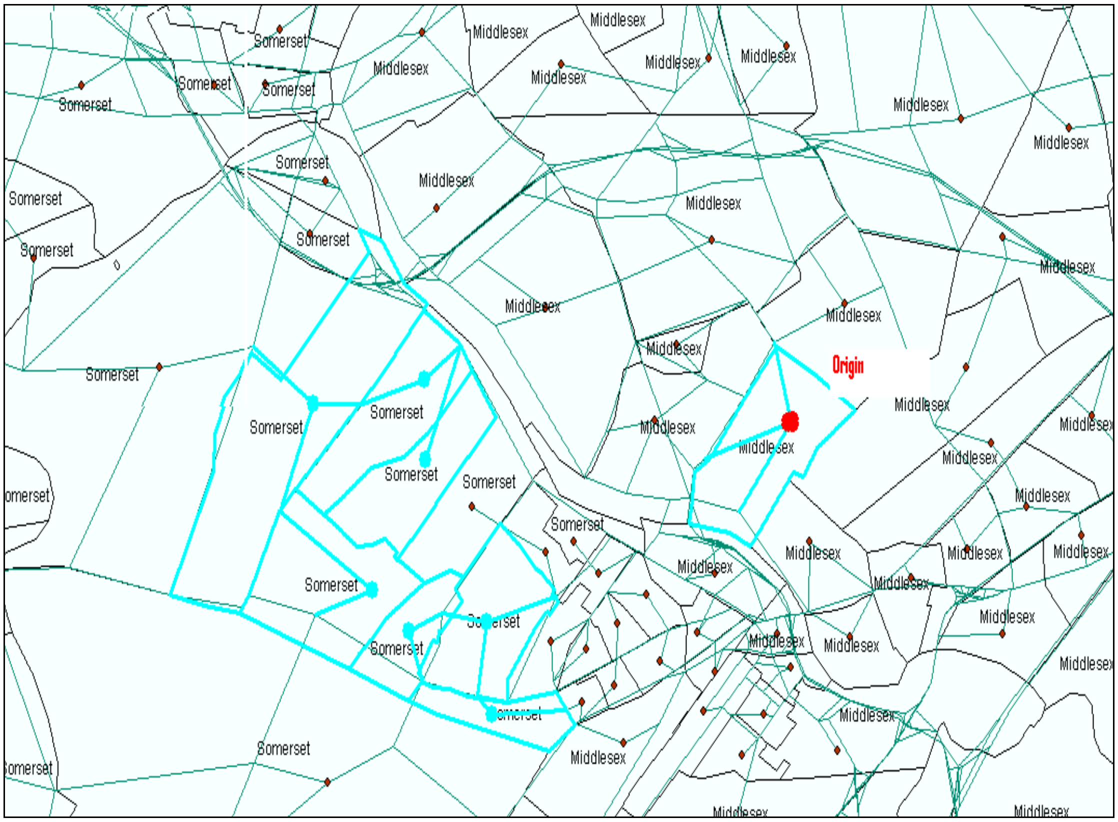

Figure 17: Selected origins and destinations in Middlesex County and Somerset County

To understand the change in accessibility from one county to another an origin TAZ is selected around the improved road section and destination TAZs are selected in the neighboring county of improved road section. Somerset County is the closest neighboring county of the modified road section. Origin of this analysis is highlighted in red color in Figure 17. The results are presented inTable 25.

Table 25: Route 18 Accessibility of the Base Network vs. the Modified Network between Middlesex County and Somerset County

O_D pair of Base & Modified Network	Travel Time (minute) of the Base Network	Travel Time (minute) of the Modified Network	Number of Employment in Destination zone	Accessibility of the Base Network (No of Jobs/min)	Accessibility of the Modified Network (No of Jobs/min)
917-1628	171.75	176.77	263	0.009	0.008
917-1634	1,695.60	1,586.79	10,417	0.004	0.004
917-1615	211.45	231.25	454	0.010	0.008
917-1622	115.22	108.6	130	0.010	0.011
917-1620	597.32	546.2	264	0.001	0.001
917-1618	614.57	408.97	1031	0.003	0.006
917-1629	218.1	165.85	2194	0.046	0.080
917-1617	435.07	296.38	2204	0.012	0.025
917-1616	324.21	205.71	42	0.000	0.001
			Total Accessibility	0.094	0.14

Table 25 shows that, total accessibility of base network is 0.094 and after the improvement it is 0.14. Hence for same origin-destination zones, accessibility of Middlesex County to Somerset County has increased by 48.9% after the improvement of Route 18. If travel time is assumed to be reduced by 10%, accessibility index value becomes 0.12 and the total accessibility would have increased by 27.65%. Thus it can be concluded that Route 18 improvement has improved the accessibility between Middlesex and Somerset County by more than 10%.

5.3.2 Case Study 2: Route 35 Victory Bridge Project

Route 35 improvement project also took place in Middlesex County, NJ. This construction was over 1.38 miles length of Route 35. One neighboring county of the improve road section of Route 35 is Monmouth County. Analysis procedure of Case Study 1 is repeated for the Route 35 Victory Bridge Project. In Figure 18 the improved road section is highlighted.

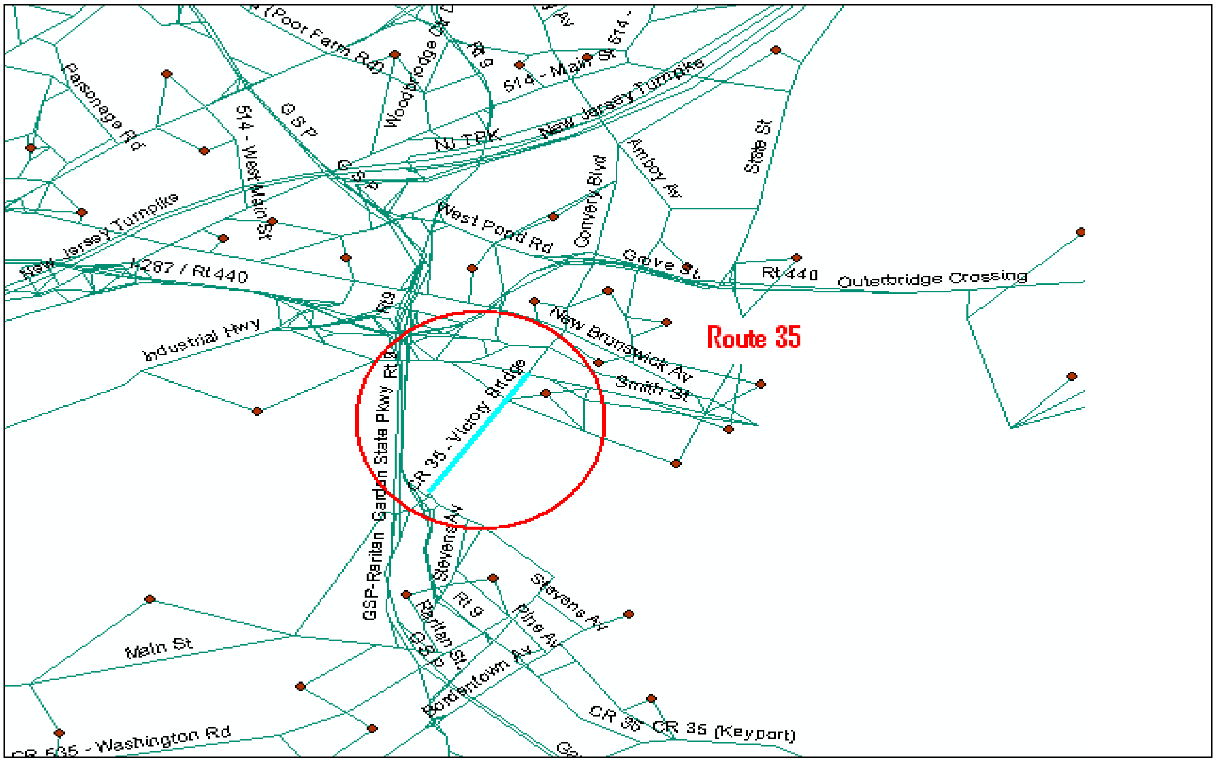

Figure 18: Route 35 improvement location

According to the procedure of accessibility calculation used in this study, the nearest TAZ of the improved road section is selected as origin and another 100 TAZs are selected as destinations within the Middlesex County in ASSIST-ME/NJCOST. This manual selection gives total 100 O-D pair trip analysis within Middlesex County. Same TAZs are selected in both original and modified network. Among the all O-D pairs, only those pairs are selected in base and modified network which have the same origin and destination TAZ. Travel times of the selected O-D pairs are compared. Origin of this analysis is highlighted in red color in Figure 19. The results are presented in Table 26.

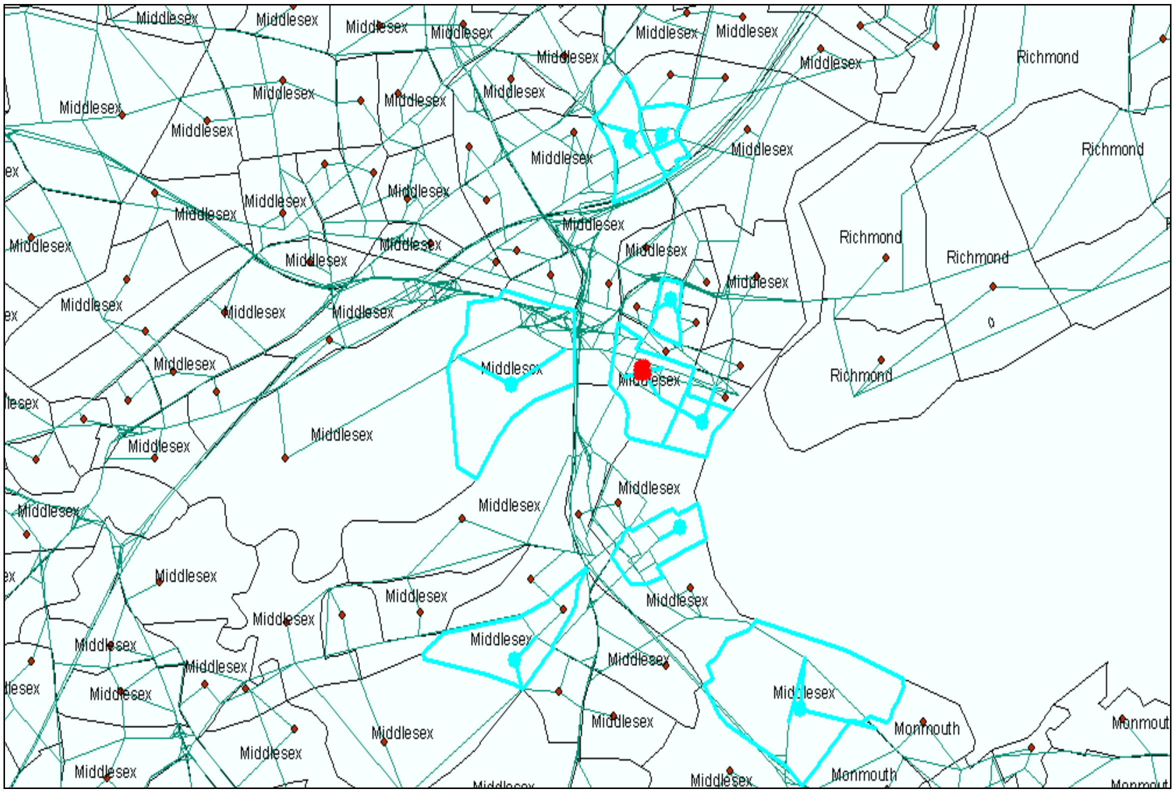

Figure 19: Selected origins and destinations in Middlesex County

Table 26: Route 35 Accessibility of the Base Network vs. the Modified Network in Middlesex County

O_D pair of Base & Modified Network	Travel Time (minute) of Base Network	Travel Time (minute) of Modified Network	Number of Employment in Destination zone	Accessibility of Base Network (No of Jobs/min)	Accessibility of Modified Network (No of Jobs/min)
996-995	297.67	291.21	2330	0.026	0.027
996-974	704.07	661.56	3923	0.008	0.009
996-1062	432.44	557.56	1468	0.008	0.005
996-998	14.33	13.65	551	2.683	2.957
996-1056	505.23	213.58	368	0.001	0.008
996-951	1,279.12	925.66	2651	0.002	0.003
996-973	699.3	485.79	1906	0.004	0.008
996-1045	446.48	217.02	1683	0.008	0.036
996-1038	295.58	153.17	1294	0.015	0.055
			Total Accessibility	2.756	3.11

Table 26 shows that, total accessibility of base network is 2.756 and after the improvement the index value is 3.11. After the improvement of Route 35 accessibility has increased by 12.84%. If travel time is assumed to be reduced by 10%, accessibility index value becomes 3.40 and the total accessibility would increased by 23.36%. Thus it is not possible for Route 35 improvement to improve the accessibility by more than 10% travel time reduction.

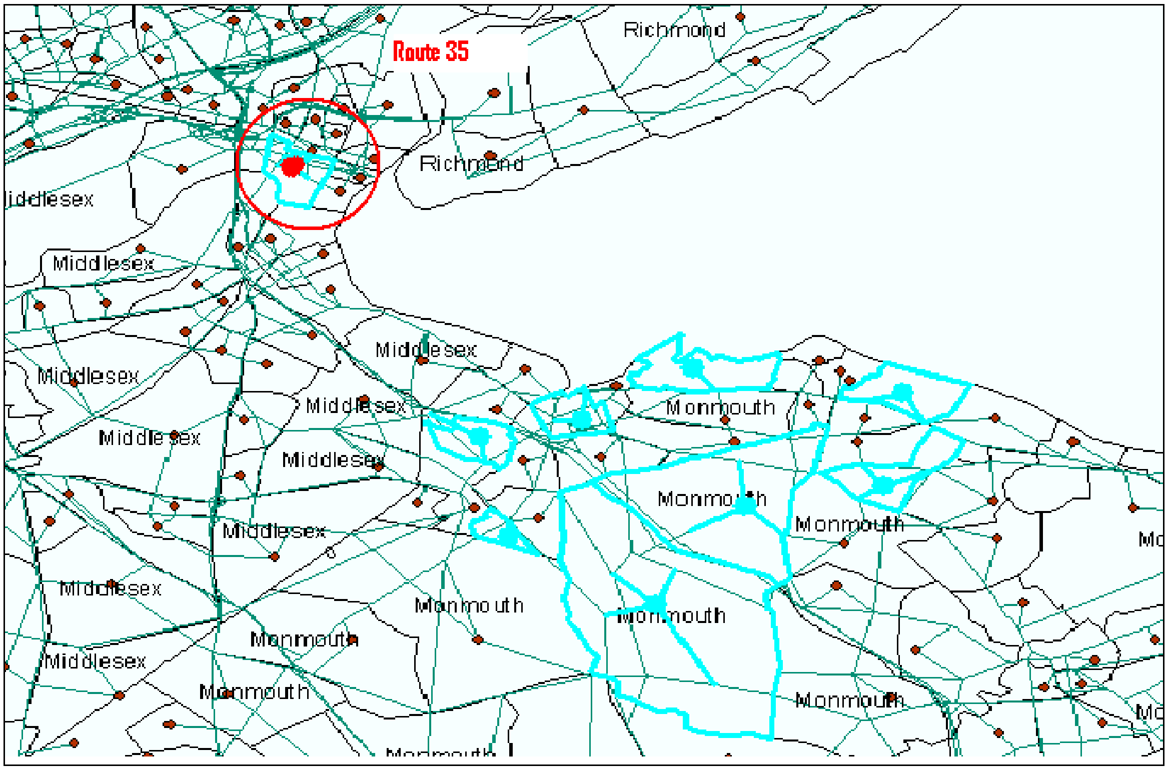

Figure 20: Selected origins and destinations in Middlesex and Monmouth Counties

To understand the change in accessibility from one county to another after improving Route 35, origin TAZ is selected around the improved road section and destinations are selected in neighboring county of the improved road section. Monmouth County is the closest neighboring of the modified road section. Figure 20 shows the selected origins and destinations of Middlesex and Monmouth Counties. The results are presented in Table 27.

Table 27: Route 35 Accessibility of Base Network vs. Modified Network between Middlesex and Monmouth Counties

O_D pair of Base & Modified Network	Travel Time (minute) of the Base Network	Travel Time (minute) of the Modified Network	Number of Employment in the Destination zone	Accessibility of the Base Network (No of Jobs/min)	Accessibility of the Modified Network (No of Jobs/min)
996-1155	733.56	722.64	458	0.001	0.001
996-1154	659.75	651.42	1265	0.003	0.003
996-1153	1,097.45	1,089.23	165	0.000	0.000
996-1148	14.33	13.65	673	3.277	3.612
996-1143	505.23	213.58	1566	0.006	0.034
996-1141	1,279.12	925.66	472	0.000	0.001
996-1157	699.3	485.79	4543	0.009	0.019
996-1145	446.48	217.02	366	0.002	0.008
996-1128	295.58	153.17	218	0.002	0.009
Total Accessibility				3.301	3.69

Table 27 shows that, total accessibility of base network is 3.301 and after the improvement the index value is 3.69. After the improvement of Route 35 accessibility has increased by 11.78%. If travel time is assumed to be reduced by 10%, accessibility index value becomes 4.08 and the total accessibility would increase by 23.59%. Thus it cannot be concluded that Route 35 improvement has improved the accessibility between Middlesex and Monmouth Counties by more than 10%.

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5.3.3 Case Study 3: Route 17 Project

Route 17 improvement project also took place in Bergen County, NJ. This construction was over 0.5 miles length of Route 35. One neighboring county of the improve road section of Route 35 is Passaic County. Same Analysis procedure is repeated for the Route 17 Project. In the following figure the improved road section is highlighted.

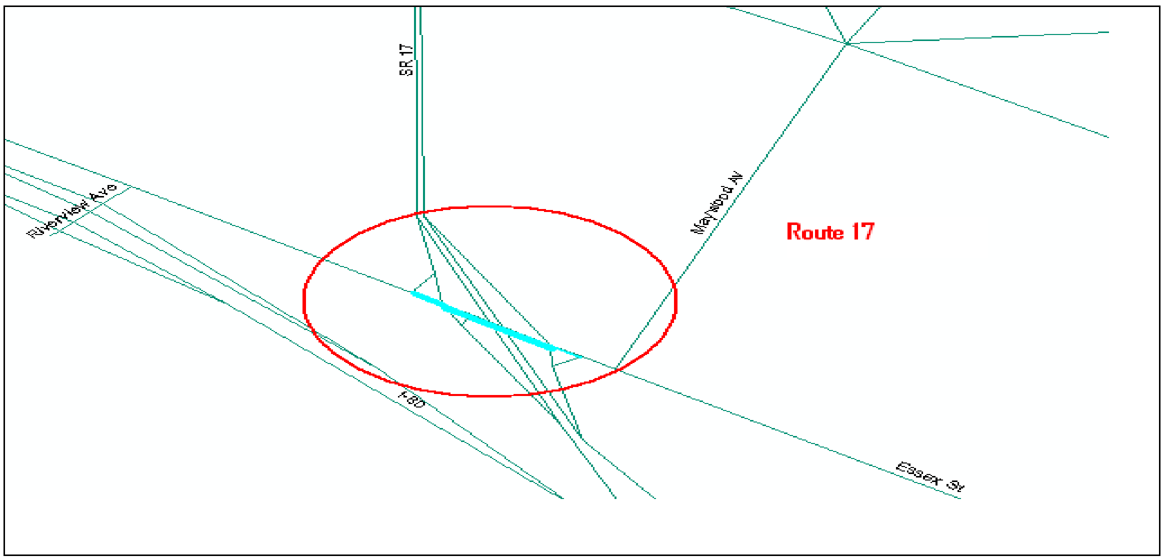

Figure 21: Route 17 improvement location

According to the procedure of accessibility calculation of this study, the nearest TAZ of the improved road section is selected as the origin and another 100 TAZs are selected as destinations within the Bergen County using ASSIST-ME/NJCOST. This manual selection gives total 100 O-D pair trip analysis within Middlesex County. Same TAZs are selected in both original and modified networks. Travel times of the selected O-D pairs are compared. Origin TAZ of this analysis is highlighted in red color in the Figure 22. The results are presented in Table 28.

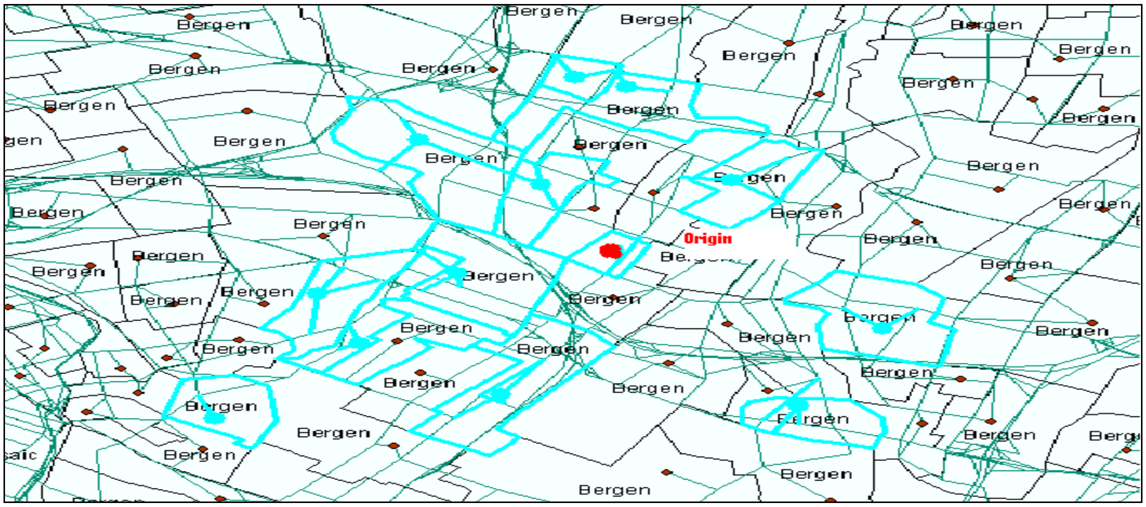

Figure 22: Selected origins and destinations of Bergen County

Table 28: Route 17 Accessibility of the Base Network vs. the Modified Network within Bergen County

O_D pair of Base & Modified Network	Travel Time (minute) of Base Network	Travel Time (minute) of Modified Network	Number of Employment in Destination zone	Accessibility of Base Network (No of Jobs/min)	Accessibility of Modified Network (No of Jobs/min)
174-168	132	124.18	5198	0.298	0.337
174-109	95.96	90.03	3038	0.330	0.375
174-100	690.38	623.76	4166	0.009	0.011
174-187	238.25	232.83	764	0.013	0.014
174-121	166.06	165.29	2497	0.091	0.091
174-110	262.4	67.21	1891	0.027	0.419
174-147	595.29	342.69	4526	0.013	0.039
174-101	704.63	646.24	1354	0.003	0.003
174-149	201.47	200.74	91	0.002	0.002
174-120	281.92	172.33	1389	0.017	0.047
174-94	296.97	201.92	112	0.001	0.003
174-111	393.52	305.71	3331	0.022	0.036
			Total Accessibility	0.826	1.376

Table 28 shows that, total accessibility of the base network is 0.826 and after the improvement it becomes 1.376. After the improvement of Route 17 accessibility has increased by 66.58%. If travel time is assumed to be reduced by 10% after the improvement, accessibility index value becomes 1.69 and the total accessibility would have increased by 22.82%. So Route 17 improvement has improved the accessibility of Bergen County by more than 10% travel time reduction.

To understand the change in accessibility from one county to another county after improving Route 17, origin TAZ is selected around the improved road section and destination TAZs are selected in a neighboring county of improved road section. Passaic County is the closest neighboring county. The results are presented in Table 29.

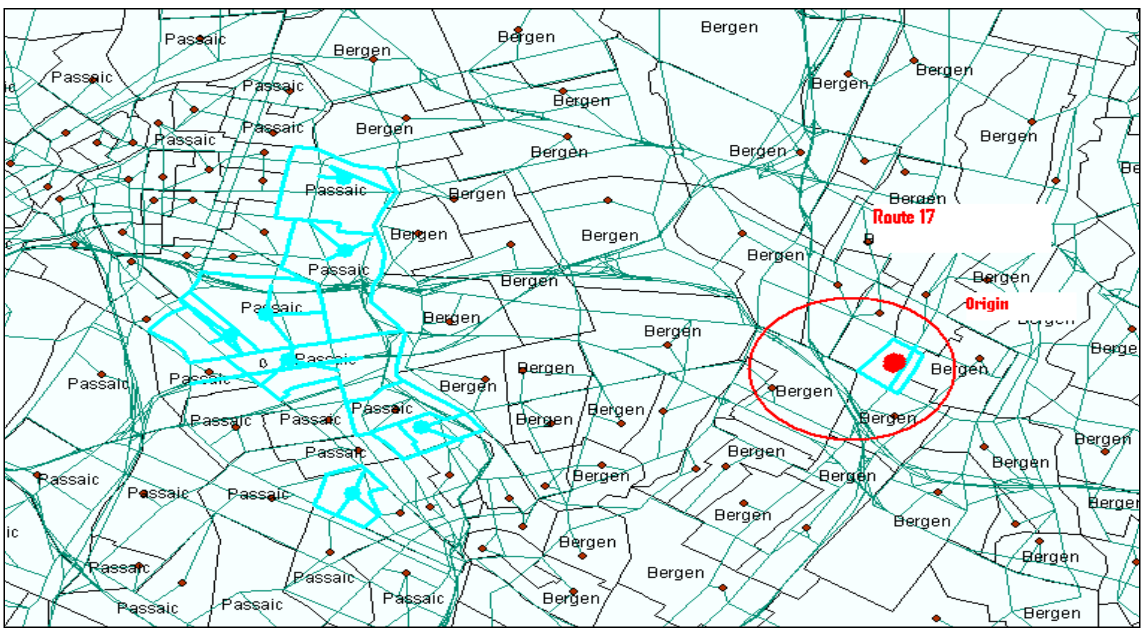

Figure 23: Selected origins and destinations in Bergen County and Passaic County

Table 29: Route 17 Accessibility of the Base Network vs. the Modified network between Bergen and Passaic Counties

O_D pair of Base & Modified Network	Travel Time (minute) of the Base Network	Travel Time (minute) of the Modified Network	Number of Employment in Destination zone	Accessibility of the Base Network (No of Jobs/min)	Accessibility of the Modified Network (No of Jobs/min)
94-1515	1,177.01	1,177.01	1,141.79	0.001	0.001
94-1548	1,226.17	1,226.17	1,113.20	0.001	0.002
94-1543	959.26	959.26	942.34	0.002	0.002
94-1544	1,226.17	1,226.17	1,013.20	0.001	0.001
94-1505	459.92	359.92	223.54	0.005	0.013
94-1530	975.23	975.23	922	0.000	0.000
94-1501	1,069.38	1,069.38	595.16	0.002	0.006
94-1549	1,046.87	1,046.87	990.82	0.003	0.003
Total Accessibility				0.015	0.028

Table 29 shows total accessibility of base network is 0.015 and after the improvement is 0.028. After the improvement of Route 17 accessibility has increased by 86.67%. If travel time is assumed to be reduced by 10% after the improvement, it becomes 0.018 and the total accessibility would have increased by 20%. Thus it can be concluded that Route 17 improvement has improved the accessibility between Bergen and Passaic Counties more than 10% travel time reduction.

5.3.4 Analysis of Accessibility Change Results

A well developed transportation system provides adequate access in a region. Accessibility measures reflect the level of service provided by transportation systems to various locations. Objective of this analysis was to observe how local improvement of an existing transportation system affects the accessibility in that region.

To understand the impact on accessibility change, three highway improvement projects are analyzed. A simplified form of Hansen's Accessibility Index is used here to calculate the accessibility change after highway improvement. Total number of employments of destination zone is used as attraction factor and travel time between origin-destination points are used as impedance factor. Origin-destination trips have generated surrounding the improved location. Then original and modified networks have compared to find the accessibility change.

Among the three case studies, Route 18 and Route 35 improvements took place in Middlesex County and Route 17 took place in Bergen County. All these case studies are analyzed separately using individual network. According to the analysis, after the improvement of Route 18, accessibility within the Middlesex County has increased by 56.42%. However, accessibility between Middlesex and Somerset Counties has increased by only 48.1%.

After the improvement of Route 35, accessibility within the Middlesex County has increased by 12.84% but Middlesex to Monmouth County has changed by 11.8%. For Route 17 improvement, accessibility of Bergen County has increased by 66.58%. However, accessibility between Bergen and Passaic Counties has increased by 86.67%.

Thus for Route 18 and Route 35 improvements, better accessibility is observed within the county of the improved location compared to the accessibility among neighboring counties. However, for Route 17 inter-county accessibility has increased more compared with the intra-county accessibility.

Overall the results show that highway improvement projects have positive impact on accessibility of the region.

6. Conclusion and Recommendation

The purpose of the study is to conduct an economic impact analysis of highway improvement projects. It is not possible to fund all highway improvement proposals because of the funding constraint. State and local authorities need to select the proposals that are expected to produce to keep pace with financial constraint. Sometimes highway improvement solutions can have serious impacts on environment and on the quality of life. It is necessary to carefully evaluate the impacts of highway improvement proposals and rank them.

A capacity expansion project can improve the traffic condition of the improved road section but at the same time it can create traffic congestion to the connected links. In that sense, any highway improvement project which produces localized benefits but not for the entire transportation network should not be considered as an appropriate solution of traffic congestion.

In this study, robust economic evaluation framework is presented to evaluate the long-term benefits of highway capital investments. The proposed methodology combines sound economic theory with the output of a highly detailed transportation demand model for estimating the costs and benefits of selected highway projects.ASSIST-ME/NJCOST software is used as a post-processor to calculate benefits based on the output of the demand model for Northern New Jersey. NJCOST can be used to calculate costs of different categories such as accident costs, vehicle operating, maintenance and environmental costs (e.g. noise and air pollution).

North Jersey Regional Transportation Model Enhanced (NJRTM-E) is also used in this study to estimate the traffic flow changes that are expected to occur on both local and network levels as a result of capacity improvements.

To test the proposed methodological framework, five major highway construction/improvement projects are selected. For each selected highway improvement project, the capacity improvement is captured in the NJRTM-E CUBE model by increasing the capacity of the link where the project took place. The NJRTM-E network is run with and without changing the capacity of specific highway links where the projects took place. The results of NJRTM-E network runs are then post-processed in the NJCOST program. The benefits of the project are estimated by the reductions in various cost categories. Total cost is estimated from the total construction cost of each project. The result of this analysis shows that, the majority of the benefits are due to reduction in congestion costs. Except for the Route 18 and Route 1&9 projects which still remain economically efficient, other projects show high benefit-cost ratios.

Usually existing road improvements are made based on the benefits in local area in which the road itself is located. While selecting the required highway improvement project, it is important to consider the network wide impacts along with the localized impacts. Sometimes a local highway improvement project can show high regional benefits without meaningful gains for entire network. Increased capacity of a certain route can create induced traffic demand and consequently the traffic pattern on the connected routes can be changed. To understand the network-wide impact of local improvements, benefit-cost analysis is conducted at different geographical levels for the selected highway improvement projects. To compute benefit-cost analysis the proposed methodological framework of highway improvement evaluation is repeated. Using ASSIST-ME/NJCOST, multiple O-D pairs are selected at different distances from the improved route section to analyze local impacts of improvements. The entire network is used to analyze the network-wide impact of improvement projects.

According to the analysis, estimated daily benefits of all projects have changed with the changing analysis boundary of the projects. Benefits increase with the greater radius around the improved location. Comparing the B/C ratios, it can be said that for localized benefits or small regional benefits Route 18 project yield more benefits than other projects. However, considering the entire network effects, Route 17 project returns the most benefits. For all the projects, total traffic volumes of the improved road sections have increased. Traffic volumes of connecting links had increased in most of the cases. However some links which are located at far away from the improved road section has shown extreme increases in volume. Reason behind this extreme change is not very clear. Overall V/C ratio has reduced to some extent in most of the regions but at some places it has increased too.

Accessibility measures reflect the level of service provided by transportation systems to various locations. To understand the impact on accessibility, a simplified form of Hansen's Accessibility Index is used to calculate the change in accessibility for each highway improvement. Total number of jobs at a destination zone is used as the attraction factor and travel time between origin-destination points are used as the impedance factor. Then original and modified networks are compared to find the accessibility change.

Among the case studies, Route 18 and Route 35 improvements took place in Middlesex County and Route 17 improvement took place in Bergen County. All these case studies are analyzed separately using the separate transportation network. According to this analysis, after the improvement of Route 18, accessibility within the Middlesex County has increased by 56.42%. However, accessibility of Middlesex County to Somerset County has increased by 48.1%. For the improvement of Route 35, accessibility within the Middlesex County has increased by 12.84% but Middlesex County to Monmouth County has changed by 11.8%. For Route 17 improvement, accessibility in Bergen County has increased by 66.58%. Between Bergen and Passaic Counties, accessibility has increased by 86.67%. Thus, for Route 18 and Route 35 improvement, better accessibility is visible within the county of the improved location compare to the accessibility of neighboring counties. However, for Route 17 inter-county accessibility has increased more compared to the intra-county accessibility. Overall the results show that highway improvement projects have impact on accessibility of the region.

This study has presented a comprehensive evaluation framework for highway improvement projects. Future research is needed to explain the reasons for the extreme change in volumes at links away from the improvement location. The analysis has shown that accessibility of the region has increased after the implementation of selected highway projects. Future studies should focus on the explanatory change in accessibility after implementing highway improvement projects.

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