Cost/Benefit Analysis of NJDOT Route 18/Hoes Lane Improvement Project

For TIGER II Grant Application

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RUTGERS

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EXECUTIVE SUMMARY

In response to USDOT's TIGER II Discretionary Grants notice the New Jersey Department of Transportation (NJDOT) is submitting the Route 18/Hoes Lane construction project for funding. Rutgers RITS Lab conducted benefit-cost analysis of the project using the output of the North Jersey Regional Transportation Model – Enhanced (NJRTM-E), which allows for estimation of the highway network-related costs of travel for the no-build and build alternatives. The benefit-cost analysis was conducted to meet the criteria put forth by USDOT, with special emphasis on the following areas:

1. State of good repair
2. Economic impacts
3. Environmental sustainability
4. Livability
5. Safety

The evaluation criteria is met by estimating the benefits of the project as the difference between the no-build and build scenarios modeled in NJRTM-E. The model output is processed and monetized into costs based on functions developed using New Jersey-specific and national data. The functions estimate costs from the network based on reductions to maintenance costs, operating costs, congestion costs, air pollution costs, noise pollution costs, and accident costs.

The cost-benefit analysis conducted weighed the cost of the project against the differences between the no-build and build estimates of the transportation model. Based on value of time guidelines of USDOT and discount rates suggested by U.S. Office of Management and Budget (USOMB) the costs and benefits are translated to present values and compared. Based on the analysis and adjusted for sensitivity, this project is estimated to have a benefit-cost ratio between 107.65 and 206.69, depending on the lower and higher values of the assumptions used. From the estimates of the regional transportation model, this project is categorized as having a positive impact to the local area and North Jersey region.

INTRODUCTION

This report describes the economic evaluation framework of the transportation-related benefits from the proposed Route 18/Hoes Lane improvement project in Piscataway, NJ. It utilizes the most important technique of public investment evaluation, *cost-benefit analysis*. Cost-benefit analysis requires the quantification and comparison of 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 (1). Benefits arise from the savings to users and society attributed to the project. The areas of focus are state of good repair, economic effects, livability, sustainability, and safety.

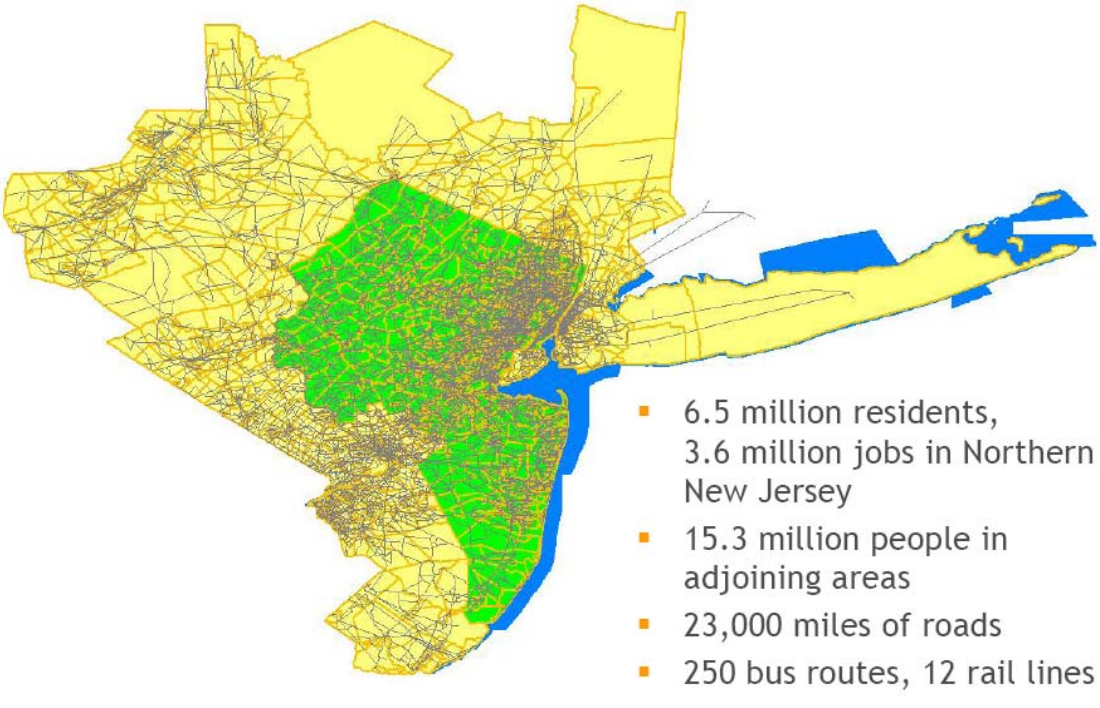
The goal of this study is to observe the benefits to the transportation system incurred due to the proposed project, with benefits from the improvement of travel conditions, which can be defined in multiple dimensions (access, time, safety, reliability, etc.). Using a transportation planning model, the North Jersey Regional Travel Model – Enhanced (NJRTM-E), scenarios of capacity improvements incurred by the proposed improvements are run and benefits calculated by modeling the proposed changes to the network, and comparing the model output with model output of the existing network. The following sections describe the NJRTM-E model and the assumptions used to model the proposed improvements. The cost-benefit evaluation process is described, including the various types of benefits quantified from the modeling process. Finally the data obtained for this study is presented and discussed.

METHODOLOGY

A major challenge in analyzing the impacts of proposed roadway changes is the estimation of the project’s effects on traffic patterns. Accordingly, it is necessary to predict the modified traffic flow in order to estimate benefits. Traditional economic analysis approaches make use of static traffic assignment to assess the impact of capacity expansion. Although these models do not consider the time-dependent dynamics of traffic flow and demand, they are superior to alternatives, such as traffic simulation tools and spreadsheet models, due to their ability to estimate the changes in network flow characteristics as a result of capacity improvements.

Transportation Network Model

The North Jersey Regional Transportation Model – Enhanced (NJRTM-E), currently used by the North Jersey Transportation Planning Authority (NJTPA), is used to estimate the changes in traffic flows that occur on both local and network levels as a result of capacity improvements. 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. NJRTM-E, shown in Figure 1, is a standard four-step transportation model running in CUBE software platform. The model area consists of the thirteen county North Jersey region and neighboring counties in New York and Pennsylvania.



- 6.5 million residents, 3.6 million jobs in Northern New Jersey
- 15.3 million people in adjoining areas
- 23,000 miles of roads
- 250 bus routes, 12 rail lines

Figure 1: NJRTM-E Region in CUBE (2)

Based on the traffic improvements expected from the roadway improvements, the capacities of the links in NJRTM-E are increased. It is, however in most cases, difficult to quantify the impact of a construction project on roadway capacity. Therefore, the capacity improvement factor is subject to sensitivity analysis.

The NJRTM-E network is run *with and without the capacity improvements*, and the network traffic flows are obtained from CUBE. Using the before and after network results, the benefits of the project are estimated by the reductions in various cost categories, such as congestion, vehicle operating, accident, air pollution, noise and maintenance costs at the network level. Accordingly, the proposed methodology combines sound economic theory with the output of a highly detailed transportation demand model for estimating the benefits to the highway network.

The results are then processed using ASSIST-ME, a tool developed to post-process highway assignment results from transportation planning models. ASSIST-ME is a GIS-based Full Cost Estimation tool that can, among its other capabilities, be used to estimate the recurring annual benefits of transportation projects. ASSIST-ME has been developed to estimate the reductions in various costs of highway transportation using cost reduction models specific to New Jersey. The GIS-based full cost estimation tool enables planners to efficiently identify areas of interest and take advantage of powerful graphical capabilities of ArcGIS.

Assumptions Used in the Analysis

As part of the TIGER Grant application, the New Jersey Department of Transportation (NJDOT) is proposing improvements to the existing Hoes Lane/Centennial Avenue corridor in Piscataway Township, Middlesex County, New Jersey. The project entails extending the current northern terminus of State Route 18 by approximately 2.5 miles to I-287 (3, 4).

In the NJRTM-E model the capacity of the links corresponding to the stretch of Hoes lane which is modified to take into account the planned capacity improvements caused by the removal of four traffic signals and updating eight traffic signals. It is estimated from the capacity calculations based on the Highway Capacity Manual that the capacity will improve by a minimum of 25% and a maximum 120%. NJTRM-E model, calibrated for the year 2009, is used as the basis for the estimation of benefits since this is the most recent network available. It is assumed that the cost estimates provided in the document “Liberty Corridor: Section 1301 Grant Submission” (3) are all given in 2010 dollars. The analysis period is limited to approximately 25 years, after which the growth in traffic will likely reach the improved capacity provided by the project. The benefit analysis is performed on a network-wide basis over the analysis period. The localized variation is traffic growth, which might be affected by various other policies such as increased transit usage, saturation in land use, etc. have not been taken into account.

ASSIST-ME Analysis Tool

Using network output files from NJRTM-E, ASSIST-ME is used to compare the two different networks (base and modified), and estimate the impacts of network changes (e.g., lane and/or link additions, etc.) on trip costs. Once highway assignment is completed in NJTRM-E, four time-period specific database files are produced. Each one of these files contains predicted values for traffic on all the links of the network. They also include basic information about all the links carried over from the input networks. This enables sorting and filtration based on their characteristics; for example, a sort can be conducted for all links within a certain state or county, or for all highway links. The calculation of link costs can be conducted in ASSIST-ME for all network links or select links by user-defined criteria. Link costs can be calculated for two networks, before and after network improvements, and the difference between the outputs can be taken as the network benefits of the improvements.

The full costs of travel in New Jersey were previously studied to quantify the effects of travel in terms of costs to users and their externalities. New Jersey-specific data was used to estimate the costs of travel when possible and national data otherwise. Calculating and monetizing the costs of travel is critical to conducting cost-benefit analysis, and understanding the full local and regional effects of the project. ASSIST-ME uses the estimated cost functions to calculate the costs of all users for all links within the transportation network, for the base and modified cases. The benefits are then taken as the difference between the costs for the two cases. A summary of the equations used by ASSIST-ME can be found in Table 1 and a full description of the costs and the development of the total cost functions is provided in the appendix.

Table 1 - Cost Functions Used in ASSIST-ME

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) m: Vehicle miles traveled	AAA [5], USDOT [6], KBB [7]
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 [8] Small and Chu [9]
Accident	*Category 1*: Interstate-freeway $C_{acc} = 127.5Q^{0.77}.M^{0.76}.L^{0.53}$ $+114.75Q^{0.85}.M^{0.75}.L^{0.49}$ $+198{,}900Q^{0.17}.M^{0.42}.L^{0.45}$	Q = Volume (veh/day) M = Path length (miles) L = no of lanes	FHWA [10] USDOT [11]
	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 $C_{acc} = 229.5Q^{0.58}.M^{0.77}.L^{0.77}$ $+9{,}179.96Q^{0.74}.M^{0.81}.L^{0.75}$		
Air pollution	$C_{air} = Q(0.01094 + 0.2155F)$ 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 [12]
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 [13]

Maintenance	$C_M = \frac{796.32M^{0.40}L^{0.39}}{P}$ where; $P = \frac{N}{ESAL}$ $ESAL = Q \times 365 \times P_t \times T_f$	*M:* roadway length (miles) *L:* number of lanes *P:* design cycle period *ESAL:* Equivalent single axle load *N:* number of allowable repetitions (1,500,000) *Q:* Traffic volume (veh/day) P_t: Percentage of trucks in traffic T_f: Truck Factor	Ozbay et al. (14)

The following subsections describe the areas in which benefits are expected, and how they are calculated. USDOT guidelines for TIGER II Discretionary Grant applications call for special attention to the following areas:

6. State of good repair
7. Economic impacts
8. Environmental sustainability
9. Livability
10. Safety

These criteria are met in cost-benefit analysis by monetizing the estimates of the regional transportation model using the functions in Table 1.

State of Good Repair

The state of roadway infrastructure is critical to vehicle operators and agencies tasked with maintaining it. The benefits to the infrastructure resulting from this project are immediately realized by the reconstructed roadway and pavement. In addition to this benefit, maintenance costs attributable to vehicles using all roadways in the network are calculated. The needs and costs for resurfacing were studied (14) to monetize the maintenance costs of links in the network, and are calculated for base and modified modeled networks. The difference in the maintenance costs (i.e. benefits) arise from changes between traffic conditions and travel patterns between the two networks.

Economic Effects

The transportation network-related effects to the economy are largely on individuals' and businesses' travel times and productivity in commuting and shipping. Transportation models calculate vehicular flows and travel times on network links, which are used as measures of congestion and vehicle hours traveled. These estimates are monetized as congestion costs by a value of time (VOT) multiplying factor, which can be different for cars, trucks, and other modes. The congestion costs for the base and modified networks are then compared to find the congestion savings brought on by the project, the most critical valuation component in cost-benefit analysis. These congestion changes can occur in the project corridor, and can spread out to parallel roadways and throughout the network. In addition, vehicle operating costs for all users are calculated.

Livability & Environmental Sustainability

Environmental effects are a critical component of transportation, and model output can be used to calculate probable environmental impacts due to changes in traffic conditions brought about the project. In this study noise and air pollution costs are estimated for all links in the base and modified networks. These costs are estimated based on volume and speed estimates generated by the model for both cases, with the difference equaling the environmental benefit of the project.

Safety

Safety improvements are a critical component of most transportation projects. In this analysis, model estimates are compared to estimate accident costs attributable to traffic using all roadways in the network. These accident costs are calculated based volumes and physical roadway characteristics.

Cost-Benefit Analysis

Even though most transportation policies are local, their influence often spreads out beyond the area of implementation. Responding to road changes, 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 (15). Thus, quantification of the likely changes in transportation benefits and costs associated with the capacity expansion is crucial for policy planners in order to determine the net benefits from capacity expansion projects. Such information can be used in the process to select the projects that are most likely to generate highest return to society.

In economic evaluation of projects, there are several commonly used economic indicators that can be placed in a final comparable format. The Cost-Benefit ratio (B/C) is one of the most commonly used performance measure. The B/C ratio can be calculated using the following formula,

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

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)

The most significant parameters in the analysis that should be tested for sensitivity are:

1. Discount rate
2. Timing of future rehabilitation activities
3. Traffic growth rate
4. Unit costs of the major construction components.

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 (USOMB) (16) are shown in Table 2. Table 3 shows the VOT ranges, as suggested by USDOT (17), used in the analysis.

Table 2 - Real discount rates for cost-benefit analysis (16)

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

Table 3 - Range of Value of Time (VOT) (17)

Time Period	Passenger Cars	Trucks
Peak	$18.10 - $27.20	$19.90
Off- Peak	$7.90 - $13.60	$19.90

RESULTS

The resulting outputs of NJRTM-E are compared in ASSIST-ME against the base case NJRTM-E model run. The daily costs and benefits resulting from the improvements due to the improvement on Hoes Lane are presented in Table 4. It should be noted that the congestion costs shown in Table 4 are estimated based on the lower bound of the VOT assumption shown in Table 3, and for a high capacity increase assumption of 120%. The capacity increase expected from this project is difficult to predict, and for this analysis is estimated between 25-120%. The results of Table 4 assume a high increase scenario. Based on the estimation results shown in Table 4, a daily benefit attributable to the Route 18 Hoes Lane project is estimated at $2.58 million. The annual benefits of this project can be calculating by multiplying this estimate by 250 workdays, and equal $646.60 million. Assuming that the benefit will linearly decrease to zero at the end of 25 years due to expected traffic increase, the net present value of the total benefits is calculated as $6.82 billion in 2009 dollars, assuming a 2.8% discount rate. Therefore, the benefit cost ratio of this project is 138.06 ($6,829.81m/$49.47m), and the project is economically efficient based on the assumptions.

Table 4 - Estimated total daily costs ($) of original and modified networks for Route 18 Hoes Lane Improvement Project

Morning Peak							
Cost Categ.	*Economic Effects*		*Safety*	*Environmental Sustainability*		*State of Good Repair*	
	Vehicle Operating	**Congestion**	**Accident**	**Air Pollution**	**Noise**	**Maintenance**	**Total**
Original	12,269,130.00	39,133,860.00	3,090,104.00	1,866,980.00	42,316.23	688,671.80	57,091,062.03
Modified	12,180,070.00	37,421,850.00	3,047,125.00	1,864,988.00	42,216.12	731,138.70	55,287,387.82
Benefit	**89,060.00**	**1,712,010.00**	**42,979.00**	**1,992.00**	**100.11**	**-42,466.90**	**1,803,674.21**
Midday Off-peak							
Original	13,290,220.00	14,092,140.00	4,131,657.00	2,538,840.00	65,369.86	1,584,298.00	35,702,524.86
Modified	13,290,610.00	14,099,900.00	4,131,771.00	2,538,690.00	65,368.71	1,583,974.00	35,710,313.71
Benefit	**-390.00**	**-7,760.00**	**-114.00**	**150.00**	**1.15**	**324.00**	**-7,788.85**
Afternoon Peak							
Original	13,737,490.00	45,214,080.00	3,422,373.00	2,054,029.00	45,853.54	740,909.60	65,214,735.14
Modified	13,704,140.00	44,652,880.00	3,407,163.00	2,052,434.00	45,828.50	741,115.40	64,603,560.90
Benefit	**33,350.00**	**561,200.00**	**15,210.00**	**1,595.00**	**25.04**	**-205.80**	**611,174.24**
Night Off-peak							
Original	9,350,579.00	9,712,229.00	3,744,627.00	1,805,579.00	46,189.01	2,293,476.00	26,952,679.01
Modified	9,335,332.00	9,562,045.00	3,726,338.00	1,799,943.00	45,674.60	2,303,977.00	26,773,309.60
Benefit	**15,247.00**	**150,184.00**	**18,289.00**	**5,636.00**	**514.41**	**-10,501.00**	**179,369.41**
Total Daily Benefit							**2,586,429.01**

Sensitivity Analysis

To evaluate the economic benefits for various combinations of ranges of VOT and capacity improvements, a sensitivity analysis is performed. This section investigates the variation in the benefit-cost ratio for the Route 18 corridor project for two values of time and capacity increase assumptions. 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 are based on the low VOT range.

The increase in capacity due to each project is 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 are based on the assumption of a high capacity increase (120%). The variation in benefit-cost ratios assuming a lower increase in capacity than initially assumed is investigated. Therefore, the factors used to increase capacity are lowered by 50% in the CUBE model, and new results are obtained accordingly (lower capacity). It should be noted that NJTRM-E model is a macroscopic model and cannot capture operational level improvements beyond capacity improvements.

The B/C ratios shown in Table 5 can be considered as an indication of the long-term economic viability of these projects, not necessarily as point estimates of their exact economic value. Moreover, over-interpretation of these B/C ratios should be avoided since there are many modeling and estimation assumptions that can affect these. A positive B/C ratio greater than an arbitrary threshold of 5 can be interpreted as a highly beneficial project.

Table 5 - Benefit/Cost ratios as a result of sensitivity analyses

High Capacity		Low Capacity	
Low VOT	*High VOT*	*Low VOT*	*High VOT*
138.06	206.69	107.65	162.03

SUMMARY AND CONCLUSIONS

The NJRTM-E network is run *with and without the capacity improvements* resulting from the proposed Route 18/Hoes Lane corridor improvement project, and the network-wide traffic flows are obtained from CUBE. The results are compiled and analyzed using ASSIST-ME, a tool capable of calculating link costs that include accident, vehicle operating, maintenance and environmental costs (e.g. noise and air pollution), based on NJ-specific data. Using the before and after results, the benefits of each project are estimated as reductions in various cost categories. A cost-benefit analysis is then conducted using USOMB and USDOT guidelines, over a lifespan for the project of 25 years. 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.

Based on the model output, this project is highly beneficial in terms of both direct user costs such as travel times, and externalities such as air and noise pollution. The results show that that the majority of benefits accrue through reduced travel times. Therefore, the benefits vary with high margins with respect to value-of-time assumptions. Sensitivity analyses conducted with respect to two variables, capacity increase and value-of-time, show that the project has a highly positive benefit-cost ratio for all cases within the range of assumptions.

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APPENDIX

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.

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, we employed the depreciation cost function estimated by Ozbay *et al*. (18)

The other cost categories, namely, cost of fuel, oil, tires, insurance, parking and tolls are obtained from appropriate AAA report (5) and USDOT report (6). The unit operating costs given in Table A1 are in 2005 dollars.

Table A1 - Operating costs (in 2005 dollars) (5,6)

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)

Congestion Costs

Congestion cost is defined as the time-loss due to traffic conditions and drivers' 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 (19). Based on a review of international studies, K. Gwilliam (20) 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 (17) 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 (21, 22, 23).

In this study, we adopt the VOT ranges based on average hourly wages as recommended by the USDOT (17). Following the USDOT, we assume two vehicle types: 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 (24) 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 A2 shows the VOT ranges, as suggested by USDOT (17), used in our analysis.

Table A2 - Value of Time Ranges

Time Period	Passenger Cars	Trucks
Peak	$18.10 - $27.20	$19.90
Off- Peak	$7.90 - $13.60	$19.90

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).

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 A3.

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.

Table A3 - Accident Cost Categories

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

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**[1]. 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 (25) reported the average unit cost per person for three accident types, as shown in Table A4. 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 A4 - Average Comprehensive Cost per person by accident type (25)

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 (26) 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 (26).

A study by FHWA (27) reported the comprehensive cost of each accident by severity, as shown in Table A5.

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[1] This approach is also consistent with previous studies e.g., Mayeres et al. (**Error! Reference source not found.**)

Table A5 - Average comprehensive cost by accident type (27)

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 (28) reported accident costs by severity. The reported figures shown in Table A6 reflect the average accident costs used by 24 states for prioritizing safety projects.

Table A6 - Average cost by accident type (28)

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 our analysis, we use the unit accident costs reported by the FHWA (27) (see Table A5). In order to align the cost estimates based on the accident types available in NJDOT accident database, we regroup accident types in FHWA (27) into fatality, injury (incapacitating) and property damage accidents. The accident cost 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*. (14), and later improved by Ozbay *et al*. (29, 18) with a new accident database. The statistical results of the estimation of accident occurrence rate functions can be found in Ozbay *et al*. (18).

Environmental Costs

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

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 is, as noted, imprecise (see Small, *et* *al.* (30)). 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 extensive literature that attempts to measure the costs of air pollution (e.g., Small (31), Small and Kazimi al.(30), Mayeres et al. (21)). 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), (Small and Kazimi (30)).

Small and Kazimi (30) 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* (PM_{10}) 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 (O_3) formation is attributed to the chemical reaction between *VOC* and NO_x. In this study, we adopt the unit cost values suggested by Small and Kazimi (30).

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 disamentity 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 (32) is defined as the ratio of the percentage reduction in housing value due to a unit change in the noise level. Nelson (32) suggests the value of *0.40*% for *NDSI*.

The noise cost 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.* (14).

Maintenance Costs

Infrastructure costs include all long-term expenditures, such as facility construction, material, labor, administration, right of way costs, regular maintenance expenditures for keeping the facility in a state of good repair, and occasional capital expenditures for traffic-flow improvement. Network properties represent the physical capabilities of the constructed highway facility, which include the number of lanes, lane width, pavement durability, intersections, ramps, overpasses, and so forth.

Maintenance and improvement constitute the only cost category that remains in our marginal infrastructure cost function. We attempt to express the maintenance cost in terms of input and output. Input in this context includes all components of maintenance work, such as equipment usage, earthwork, grading, material, and labor. Output implies the traffic volume on the roadway. The data employed include completed or ongoing resurfacing works between 2004 and 2006 in New Jersey.

P factor represents the time period (in years) between two consecutive resurfacing improvement works. *ESAL* converts the axle loads of various magnitudes and repetitions to an equivalent number of “standard” of “equivalent” loads based on the amount of damage they do the pavement (57). Truck factor changes with respect to different road types. Values for various road types are provided in Table A7.

Table A7 – Truck factor values

Road Type	**Area Type**	
	Rural	Urban
Interstate	0.52	0.39
Freeway	-	0.23
Principal	0.38	0.21
Minor Arterial	0.21	0.07
Major Collector	0.3	0.24
Minor Collector	0.12	