Cost/Benefit Analysis of NJDOT Route 23 Sussex Borough Realignment and Papakating Creek Bridge Replacement Project

For TIGER II Grant Application

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RUTGERS

Rutgers Intelligent Transportation Systems Laboratory (RITS)
Rutgers, The State University of New Jersey
CoRE Building 7th Floor, Busch Campus
96 Frelinghuysen Rd, Piscataway, NJ 08854
http://rits.rutgers.edu

EXECUTIVE SUMMARY

In response to USDOT's TIGER II Discretionary Grants notice the New Jersey Department of Transportation (NJDOT) is submitting the Route 23 Sussex borough realignment and Papakating Creek bridge replacement project for funding. Rutgers RITS Lab conducted benefit-cost analysis of the project by estimating 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 Synchro and NJRTM-E, the regional travel demand model for Northern New Jersey. 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, by forecasting the direct benefits of the Route 23 realignment, as well as the potential costs of closure of the Papakating Creek bridge due to structural failure or emergency repairs, and its effect to the entire regional network. Based on value of time guidelines of USDOT and discount rates suggested by U.S. Office of Management and Budget the costs and benefits are translated to present values and compared. When considering the transportation-related impacts only, this project is estimated to have a benefit-cost ratio of 0.80 – 1.15, depending on the value of time the assumption.

INTRODUCTION

This report describes the economic evaluation framework of the transportation-related benefits from the proposed Route 23 Sussex borough realignment and Papakating Creek bridge replacement project. The goal of this study is to observe the benefits to the transportation system incurred by changes to Route 23 to the local area and region-wide, to conduct cost-benefit analysis to evaluate the project's viability. 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, and 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, with transportation-related benefits in terms of the improvement of travel conditions, which can be defined in multiple dimensions (access, time, safety, reliability, etc.). As per USDOT guidelines, the areas of focus for transportation projects are impacts to the state of good repair, economy, livability, sustainability, and safety.

Using local traffic network analysis conducted by PB Americas, Inc. [(2)] and a transportation planning model, the North Jersey Regional Travel Model – Enhanced (NJRTM-E), the proposed improvements are modeled and the existing (no-build) and modified (build) cases are compared. Cost-benefit analysis is conducted from the output of both models on two fronts: the long-term benefits of the Route 23 realignment to the roadway network, and the short-term impacts of the Papakating Creek bridge replacement. The short-term impacts of the bridge replacement are calculated by modeling a what-if scenario, of the impact to the regional transportation network if the bridge were to be closed for a period of time due to structural failure or any emergency repairs.

The following sections describe the assumptions used to model the proposed improvements, and the NJRTM-E model. The cost-benefit evaluation process is described, including the various types of benefits quantified from the new modeling and previous work. Finally the results of the cost-benefit analysis are presented and discussed for project evaluation.

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 models 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.

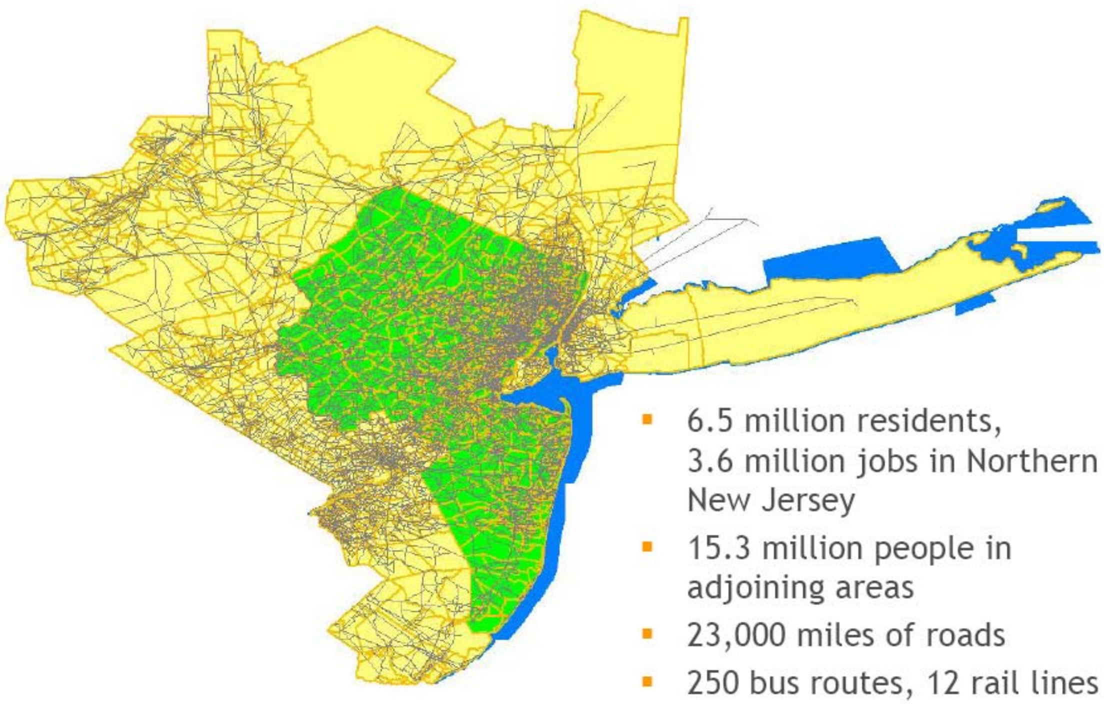

Figure 1: NJRTM-E Region in CUBE [3]

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.

Assumptions Used in the Analysis

NJRTM-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. 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. The previous studies conducted on traffic effects [(2)] are on a local level, whereas this model is regional and macroscopic in nature. Typical regional transportation models do not account for additions such as bike lanes and streetscaping and even traffic improvements such as turning lanes and signal timings are not explicitly captured in a macroscopic model such as NJRTM-E. However capacity improvements are made to links in the model as per highway capacity manual guidelines with the proposed roadway network changes conservatively estimated to result in a 15-30% capacity increase.

The NJRTM-E network is run *with and without the capacity improvements*, and the network traffic flows are obtained from CUBE. Running of the entire network model, including new trip generation and distribution processes were not run. Thus localized variation is traffic growth, which might be affected by various other policies, saturation in land use, etc. have not been taken into account. For this project, the capacity increases coded in NJRTM-E did not result in any significant differences in assignment output between the base case and build scenarios. One reason for this is that in the macroscopic model, capacity on this section is already considered as under-utilized, so increasing capacity did not provide any better conditions. Being a macroscopic model, geometric and operational features cannot be accounted for, thus these changes are not observed to have any impact. Synchro analysis previously conducted for this corridor by PB Americas, Inc. [(2)] is on a more detailed and local scale than the NJRTM-E model. Accordingly, these networks are more appropriate for estimating the impacts of this project.

The results are 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, or national data if NJ-specific data were unavailable. ASSIST-ME is designed to process output of transportation planning models such as NJRTM-E, but is adapted to convert Synchro output into costs for cost-benefit analysis for this study. Using the before and after network results (for the base year), 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. 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.

ASSIST-ME Analysis Tool

Using network output files from the traffic analysis, ASSIST-ME is used to compare the two different networks (base and modified), and estimate the impacts on trip costs. 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 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*) + 2783.3*a* + 0.143*m*	a: Vehicle age (years) m: Vehicle miles traveled	AAA [4], USDOT [5], KBB [6]
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 [7] Small and Chu [8]
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 [9] USDOT [10]
	Category 2: principal arterial EMBED Equation.3		
	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 [11]
Noise	$C_{noise} = 2\int_{r_1=50}^{r_2=r_{max}} (L_{eq}-50)DW_{avg}\frac{RD}{5280}dr$ where; $K = K_{car} + K_{truck}$ $K = \frac{F_c}{V_c}\left(V_c^{4.174}.10^{0.115} + 10^{5.03F_{ac}+(1-F_{ac})6.7}\right) + \frac{F_{tr}}{V_{tr}}\left(V_{tr}^{3.588}.10^{2.102} + 10^{7.43F_{atr}+(1-F_{atr})7.4}\right)$	*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	Delucchi and Hsu [12]

	$L_{eq} = 10\log(Q) + 10\log(K) - 10\log(r) + 1.14$	F_{ac} =% const. speed autos F_{atr}=% of const. speed tr. V_c = Auto Speed (mph) V_{tr} = Truck Speed (mph)	
Maint- enance	$C_M = \frac{796.32M^{0.40}L^{0.39}}{P}$ 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. [13]

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:

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

These criteria are met in cost-benefit analysis by monetizing the estimates of the traffic models using the functions in Table 1.

<u>State of Good Repair</u>

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 roadways and their pavement. In addition to this benefit, maintenance costs attributable to vehicles using Route 23 and adjacent roadways in the network are calculated. The needs and costs for resurfacing were studied [13] 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. The analysis thus calculates the cost of maintenance that will be due for the roadways due to the vehicles using them.

Additionally, this project proposes replacing the Papakating Creek Bridge. While the cost of bridge replacement is significant, the impact to the network if the bridge were unusable would be substantial. Either due to structural failure or emergency closure for repairs at the end of the bridge's life, a bridge closure scenario is modeled in NJRTM-E to observe the impact of losing the link has on the entire regional transportation network. The short-term impacts of bridge closure are then monetized based on assumed closure periods, by comparing the total network costs of the base-case with the closure case.

Economic Effects

The transportation-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 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 the no-build and build 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. In addition, NJDOT crash statistics are analyzed for recent years to determine the number of crashes on the existing network. Using FHWA guidelines [9, 15], the proposed improvements' effects on the safety and crash probability of Route 23 are analyzed and converted to cost savings.

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 [14]. 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:

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

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. **Error! Reference source not found.** 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 model outputs of the build network are compared in ASSIST-ME against the base case network. The cost-benefit analysis is conducted separately for the two main components of the benefits of this project: Route 23 realignment and potential Papakating Creek bridge closure scenario. The total cost of this project including both the Route 23 realignment and Papakating Creek bridge replacement is estimated at $25 million [2]. The following subsections break down the benefit estimates. It should be noted that the benefits calculated in this report only account for the transportation-related impacts of this project. While the Papakating Creek bridge closure scenario's benefits are calculated throughout the NJRTM-E network (North Jersey region), the Route 23 realignment's benefits are only calculated for the Synchro network of Sussex borough.

Route 23 Realignment Benefits

The benefits related to the street improvements of Route 23 in Sussex borough are calculated as the difference between the costs of the build vs. no-build Synchro base networks. Networks are available for the AM Peak, Midday, and PM Peak periods It is assumed that the impacts will be observed for 13 hours of the day, corresponding to these networks (6am – 7pm), and no network benefits are observed during the overnight period. The networks themselves include Route 23 through Sussex borough and the adjacent intersecting roadways. Costs are calculated for all links in the networks, and the benefits are taken as the difference in costs between the build and no-build networks. The impacts are seen by the realignment of Route 23 southbound onto a separate one-way road, large shoulders, and signal improvements. As described, ASSIST-ME calculates maintenance costs, operating costs, congestion costs, noise and air pollution costs, and accident costs, which correspond to social benefits to the state of good repair, the economy, environmental sustainability, and safety.

The congestion-related economic impacts are calculated as the cost to users, i.e., vehicle operating and congestion costs. Time spent in congestion is the largest contributor to travel costs, and is very sensitive to the value of time (VOT) assumption used. Accordingly, benefit estimates are produced for the lower and upper bounds of VOT shown in Table 3. The results in Table 4 indicate that the Route 23 realignment has a positive benefit on network and user costs in Sussex borough. The daily costs for vehicles in the network and their externalities are decreasing between $1,200 and

$2,000 per day depending on the value of time assumption. Accordingly, assuming benefits are seen for 250 workdays in the year, annual savings are $300,000-500,000.

Table 4 – Daily and annual benefits from Synchro network ($)

	Daily Costs		Annual Costs	
	Low VOT	***High VOT***	***Low VOT***	***High VOT***
No-build	$10,970	$14,953	$2,742,396	$3,738,340
Build	$9,701	$12,953	$2,425,178	$3,238,247
Benefit	*$1,269*	*$2,000*	*$317,218*	*$500,094*

Additional safety benefits are measured by the mitigation of accident costs due to the new alignment not captured by the accident cost estimation in ASSIST-ME. According to crash records for this section of Route 23 (2) there were 90 accidents on this section between 2005 and 2007, 14 of which were injury accidents. According to FHWA guidelines (27), accidents costs can be monetized according to Table 5. Additionally, FHWA provides guidelines on the accident mitigation potential of safety improvements to roadways (15). Conversion of a two-way roadway into a one-way roadway, the most significant operational change of this project, can potentially reduce accidents by 43%. There are reduction factors for many other safety features of this project, including wider shoulders and a new bridge deck, thus the accident reduction factor of this project is conservatively taken as 50%. Table 6 calculates the potential annual accident cost savings due to the realignment of this project based on 2005-2007 accident rates.

Table 5 - 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.

Table 6 - Average annual accident cost ($)

Type of Accident Cost	2005	2006	2007	Average
Property Damage Accident Cost	$53,694	$76,302	$84,780	$71,592
Injuries Accident Cost	$310,856	$155,428	$77,714	$181,333
Fatalities Accident Cost	$0	$0	$0	$0
Total Accident Cost	*$364,550*	*$231,730*	*$162,494*	*$252,925*
50% Accident Reduction Savings				***$126,462***

Papakating Creek Bridge Closure Scenario

This project repairs the Papakating Creek Bridge carrying Route 23 into Sussex borough, so benefits are calculated for mitigation of a potential emergency bridge closure if the bridge was not repaired. Assuming structural failure or emergency repairs on the bridge, the bridge could have to be closed for a short period, and traffic would have to temporarily re-route itself on other roadways. Resulting impacts on other roads would increase congestion and lengthen trips that were shorter or faster on Route 23. This scenario was modeled in NJRTM-E highway assignment to determine how traffic would re-route itself and the costs for links in the network calculated and compared to the base case. The difference in costs can be seen in Table 7, and the total network costs calculated assuming a closure period of one year (counting for 250 workdays).

Table 7 – Daily and total cost of bridge closure scenario ($)

	Daily Costs		**1-year Closure Cost**	
	Low VOT	***High VOT***	***Low VOT***	***High VOT***
Base	$184,522,870	$243,908,278	$46,130,717,430	$60,997,069,430
Bridge Closure	$784,583,925	$243,996,864	$46,145,981,348	$60,999,216,098
Benefit	*$61,056*	*$88,587*	*$15,263,918*	*$22,146,668*

Cost-Benefit Analysis

Cost-benefit analysis due to transportation network-related effects is conducted for the roadway-related improvements and the bridge closure aversion components of this analysis. First the daily Route 23 realignment estimates are annualized by multiplying by 250, roughly equivalent to the number of workdays in a year. Then the benefits are discounted over future years according to the USOMB guidelines shown in Table 2. It is assumed that the benefits linearly decrease to zero over 25 years, by which time the increase in traffic volume is expected to counterbalance the benefits. The Papakating Creek bridge closure aversion is taken at a one-time one-year cost savings. Table 8 shows the benefits of both project components using a 2.8% discount rate, for a period of 25 years. It is assumed that after 25 years, the benefits have decreased to zero due to traffic growth.

Table 7 – Benefits and costs for 25-year analysis period ($)

	Estimated Project Cost	Benefits	
		Low VOT	***High VOT***
Route 23 Realignment	$25,000,000	$4,686,367	$6,617,992
Avert Bridge Closure		$15,263,918	$22,146,668
Total Project		*$19,950,285*	*$28,764,660*

The cost benefit (B/C) ratios for this project using conservative and high values of time are produced in Table 8. The B/C ratios shown in Table 10 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. Additionally, these B/C ratios only include the transportation-related benefits of this project. A B/C ratio greater than 1 indicates a beneficial project, thus this project can be considered as beneficial to the transportation network of Sussex and Northern New Jersey depending on the assumptions used. Even using conservative assumptions, the B/C ratio is close to 1.

Table 10 - Benefit/Cost ratios as a result of sensitivity analyses

	Low VOT	*High VOT*
B/C Ratio	*0.80*	*1.15*

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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 [(4)] and USDOT report [(5)]. The unit operating costs given in Table A1 are in 2005 dollars.

Table A1 - Operating costs (in 2005 dollars) [(4, 5)]

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.

[1] This approach is also consistent with previous studies e.g., Mayeres et al. (21)

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*. [13], 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 et 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* (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, we adopt the unit cost values suggested by Small and Kazimi [30].

<u>Noise Costs</u>

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.* [13].

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. 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	