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ESTIMATION AND EVALUATION OF FULL MARGINAL COSTS OF HIGHWAY TRANSPORTATION IN NEW JERSEY

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Abstract

In this study we present a methodology for estimating full marginal transportation costs of highway transportation in New Jersey. This methodology is specifically applied to northern New Jersey highway network. We reviewed the existing studies, and identified the highway transportation cost categories. Cost functions are developed using NJ specific data for each cost category. Along with the total cost functions, marginal costs functions are derived as well. These marginal cost functions are used in the application of our full marginal cost estimation methodology. Finally, the resulting marginal cost values for northern New Jersey are analyzed according to various trips distances, urbanization degrees and highway functional types.

Keywords: Marginal cost estimation; Highway transportation cost; Total cost; Highway networks
Topic Area: H9 Implementation of Pricing in Transport

1. Introduction

At the heart of many congestion mitigation options lies the accurate estimation of full marginal highway travel costs to the State. This information is essential for allocating resources efficiently, for ensuring equity among users of different transportation mode users, and for developing effective pricing mechanism. Full Marginal Costs (FMC) means the overall costs accrued to society from servicing an additional unit of user. *FMC* include capital costs, maintenance costs, highway accident costs, congestions costs and environmental costs.

This paper is mainly concerned with the estimation of *FMC* of highway transportation in New Jersey and the analysis of these cost models by applying them to Northern New Jersey network.

This paper has two major objectives:

1. Develop a general cost model to estimate the full costs of highway passenger transportation using New Jersey (NJ) specific data.
2. Apply this cost model to Northern NJ highway network to estimate the factors that affect the full cost of highway transportation in the study area. The results of this second step are amenable to policy interpretation aimed at developing efficient policies to improve the performance of the NJ transportation system.

The full cost of highway transportation costs are usually categorized as "Direct" and "Indirect" costs. **Direct costs** (sometimes called private or internal costs) include the costs that auto users directly consider as monetary losses, such as vehicle operating cost, car depreciation, time lost in the traffic, infrastructure cost (through taxes), etc. **Indirect costs** (also called social or external costs), on the other hand, refer to the costs that auto users are not held accountable for. This includes the costs that every user imposes on the rest of the traffic, including the costs of congestion, accidents, air pollution, and noise. Following an extensive literature review the costs categories identified as well as data sources are shown in Table 1.

Table 1 Major Cost Categories and Data Sources

Cost Categories	*Payer*	*Data Sources*
Vehicle Operating Costs • Auto Ownership • Auto Operations (Gasoline + Maintenance + Insurance) • Tolls • Insurance	Private	NJDOT, Internet Resources (Kelley Blue Book online), American Automobile Manufacturers Association (AAMA)
Infrastructure Costs • Capital • Maintenance & Improvements • Right-of Way	Public	NJDOT
Environmental Costs • Air Pollution • Noise	Public & Private	Existing Studies & NJDOT, Environmental Protection Agency (EPA)
Congestion Costs • Travel Time	Private	NJDOT
Accident & Safety Costs • Bodily & Property Damage • Productivity • Emergency & Medical Services (Police + Ambulance + Rescue)	Public & Private	NJDOT

Most of the previous studies which deal with the estimation of transportation costs mainly focus on the average cost of highway transportation (Tellis and Khisty, 1995; Churchill, 1972; Cipriani et al., 1998; Peat Marwick Stevenson & Kellog Technical Report, 1993; TRB Report, 1996). On the other hand, only few studies deal with the estimation of marginal costs (Levinson et al., 1996, 1998; Mayeres et al., 1996). Levinson et al. (1996), deal with both marginal and full costs of supplying transportation services. Mayeres et al. (1996), deal with the estimation of marginal external costs only. The "British Columbia Lower Mainland" study (PMSK, 1993) uses societal costs such as cost of roadway land value, cost of air and water pollution, cost accidents, and cost of loss of open space, and user costs

The importance of focusing on the marginal of service provision in a given area stems from the fact that marginal costs measure the actual increase in costs due to an additional mile (or trip) traveled. Thus they represent the additional costs that the State should consider to encourage efficient transportation use. Although traditional government cost allocation studies have evolved over the years to incorporate concepts similar to marginal costing, non-governmental costs are still largely ignored. However, cost of congestion, pollution, and accidents are real costs to the government as well as to the society. Therefore, they should be considered while estimating the cost of transporting people. In brief, marginal cost approach by including external costs that are practically measurable tends to be more realistic in estimating the real costs of transportation.

The design of this paper is as follows. Section 2 describes the methodology used to estimate the marginal cost functions. Section 3 explains the marginal cost functions developed for each cost category and New Jersey specific data used in the analysis. Main results are presented in Section 4. In Section 5, the current pricing policy in NJ is evaluated based on the estimated marginal cost functions. Finally, Section 6 presents the conclusions.

2. Proposed marginal cost estimation methodology

In this paper we consider the common case where the marginal cost of highway travel is higher than the average cost, which reflects that an additional vehicle in the traffic imposes a definite cost on all users (Mohring, 1976). Figure 1 demonstrates this specific case. Due to the lack of a correct pricing policy that sets price to users equal Full Marginal Costs (*FMC*), highway transportation infrastructures are over utilized, auto and truck users do not pay for what they use, and the cost of serving an additional trip to society is higher than the average cost at that demand level[1] (See point *A* in Figure 1).

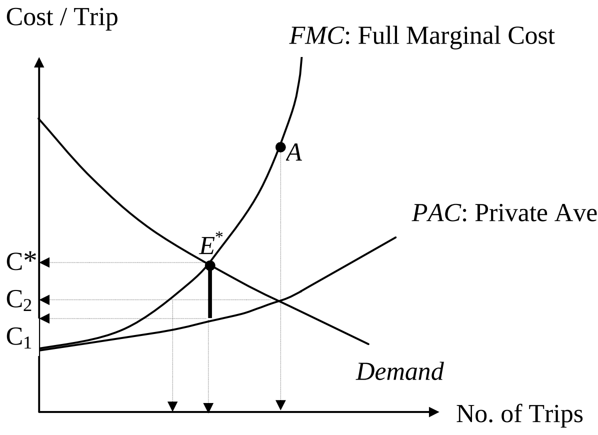

Figure 1 Hypothetical Marginal and Average Costs of highway transportation

Formulation of *FMC*: Cost of making a trip between Origin-Destination (O-D) pairs in a network is a function of several variables, here denoted by V_j. The average cost C_{rs}, of "one trip" traveled between a specific O-D pair (r, s) is as follows:

$$C_{rs} = F(V_j; q) \tag{1}$$

where, $\boldsymbol{q}$ denotes the demand between the O-D pair We assume that there are $\boldsymbol{q}$ number of homogeneous users who make the same trip over a given time period[2]. Full Total Cost (*FTC*) of providing a transportation service between any O-D pair for $\boldsymbol{q}$ trips **is** defined as follows:

$$FTC_{rs} = q.(C_{rs}) = q.F(V_j; q) \tag{2}$$

From (3), we obtain *FMC* for each O-D pair (r, s) over a given time period as follows:

$$FMC_{rs} = \frac{\partial(q.F(V_j; q))}{\partial q} = F(V_j; q) + q.\frac{\partial F(V_j; q)}{\partial q} \tag{3}$$

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[1] Here, we assume that highway prices are most likely equal to average cost after complex political considerations and processes.

[2] The term "user" is used here to connote a vehicle trip.

This function gives the cost of adding an extra trip to the system. The first term represents the average cost and the second term represents the additional cost of a trip. Thus, if we add one more user making an extra trip, the cost imposed by an additional trip to the rest of the traffic is $q.(\partial F(V_j;q)/\partial q)$. This cost amount is an "externality"; and we refer to this term as "congestion related costs." In Figure 1, the difference C^*-C_1, is equal to this term.

Thus, we define *FMC* of an additional trip as:

FMC **($) = Private Average Cost ($) + Congestion Related Costs ($)**

In terms of Figure 1, computation of *FMC* is at the point of social equilibrium" (E^*), where C^* is the optimal price. If the optimal cost is determined by setting the tolls equal to *FMC* evaluted at q^*, $\partial FTC(q^*)/\partial q$, then the total revenue of tolls (*TR*) will be (Small, 1992):

$$TR = (\frac{\partial FTC(q^*)}{\partial q}).q^* = \frac{1}{s}.FTC \tag{4}$$

Where *FTC* is full total cost, *q* is the demand and *s* is the degree of economies of scale. Equation (4) implies the known rule that total cost will be covered if $s \leq 1$ (s=*AC*/*MC*, where *AC* is average cost and *MC* is marginal cost). As mentioned before since marginal cost is usually higher than average cost for highly congested highways, the toll revenue compensates the full total cost of highway transportation even when no fuel tax is charged.

One problem in defining *FMC* is that in reality highway travel is a complicated phenomenon as users attempt to minimize their individual travel costs. They change their routes and time of travel constantly depending on the network attributes (i.e. travel demand, number of routes between each origin destination pair, capacity of each link, etc). Hence, if additional demand between a given origin-destination (O-D) pair is introduced, not only will the travel patterns on each route connecting that O-D pair change, but travel patterns on all other routes in the network will also change. The solution to this problem is to add an extra trip (vehicle) along the shortest route of each O-D pair in the network. Since each shortest path between the O-D pairs has different characteristics (i.e. distance, urbanization, highway type, time of the day, etc) the FMC analysis requires the classification of the calculated FMC with respect to the trip attributes.[3]

To simplify analysis, without loss of generality in this paper, only one route rather than the entire network is considered. Therefore, it can be assumes that the selected O-D pair is independent of from the network, thereby greatly simplifying the calculation of the FMC. We refer this marginal cost as **One-Route Marginal Cost** (*ORMC*)

Next we explain the marginal cost functions developed for each cost category as well as the data used in the analysis.

3. Cost functions and data specification

This section explains the cost categories and presents the data used for the estimation of the specific cost functions. These functions are based on analysis done by Ozbay et al. (2000).

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[3] For a detailed description of the analysis, readers may refer to Ozbay et al. (2001).

The cost categories are (1) Vehicle operating costs, (2) congestion costs, (3) accident costs, (4) infrastructure costs and (5) environmental costs

A specific cost function have been estimated for each category based on data obtained from the NJDOT and from the other available sources. It should be noted that data on vehicle operating costs, accident costs, and infrastructure costs are NJ specific. Whereas, congestion and environmental costs are adopted from relevant studies in the literature but their parameters have been modified to fit NJ conditions.

Table 2 lists the estimated marginal highway cost functions used in our analyses.

Table 2. Marginal Cost Functions (Ozbay et al, 2000)

Cost Categories	**Marginal Cost Function**		**Variable Definitions**
Vehicle Operating Cost		$MC_{opr} = 0.1227 + \left(\frac{0.104}{a}\right)$	a: Vehicle Age (years)
Congestion Cost		$MC_{cong} = T_{ab}.(VOT) + Q.(VOT).\frac{\partial T_{ab}}{\partial Q}$	T_{ab}:Travel Time between a, b (hr) VOT: Value of Time (\$/hr) Q: Traffic Volume (veh/hr)
Accident Cost	Arterial-Local-Collector	$MC_{acc} = (0.007).M^{0.4592}.Q^{1.1937} + (125.58).M^{0.8945}.Q^{-0.2643} + (0.0022).M^{0.7366}.Q^{1.5084}$	M: Highway Length (miles) Q: Traffic Volume (veh/hr)
	Freeway-Expressway	$MC_{acc} = (89.81).M^{0.2317}.Q^{-0.05} + (18237.87).M^{0.501}.Q^{-0.3163}$	
	Interstate	$MC_{acc} = (0.2394).M^{0.9043}.Q^{0.0924} + (9.42.10^{-5}).M^{0.9766}.Q^{1.0963}$	
Infrastructure Cost		$MC_{inf} = 1.2931.Q^{0.2931}.\sum_{i=1}^{T}\frac{r}{1-e^{-r.n_i}}$	Q: Traffic Volume (veh/day) T: Number of resurfacing cycles throughout the lifetime of a pavement n_i: Time interval between each resurfacing dates and year 2000 (years). r: Interest rate.
Air Pollution Cost		$MC_{air} = 0.01094 + 0.2155.(F + Q.\frac{\partial F}{\partial Q})$ Where, $F = 0.0723 - 0.00312.V + 5.403.10^{-5}.V^2$	Q: Traffic Volume (veh/day) F: Fuel Consumption at cruising speed (gallons/mile)
Noise Cost		$MC_{noise} = \frac{RD.(r_2 - r_1).W_{avg}}{2640}.\left(\frac{10}{Q.\ln 10} + \frac{20.(\partial V/\partial Q)}{(V).\ln 10}\right)$ Where, $L_{eq} = 10.\log Q - 10.\log r + 20.\log V + 20$	Q: Traffic flow (veh/hr), R: Distance to the highway (feet), V: Average speed of the traffic (mph), r_2:Maximum distance affected by noise (feet) r_1: Minimum distance to highway (feet) N_h: Number of houses effected (number of houses per $mile^2$) W_{avg}: Average house value (\$) L_{eq}: Equivalent Sound Level (dB(A))

3.1. Vehicle operating costs

Vehicle operating costs are directly borne by drivers. They include fuel and oil consumption, expected and unexpected maintenance; wear and tear, insurance, parking fees and tolls, and automobile depreciation. All of these costs can be expressed as a function of annual kilometer traveled for a given the make and age of car. In this cost model, operating costs, insurance, parking and toll costs are taken from the American Automobile Manufacturers Association (AAMA Annual Report 1996) and USDOT (Cost of Owning and Operating Automobiles, Vans and Trucks 1995). These values are given in Table 3. These costs are assumed to be uniform relative to car make and age. Depreciation, on the other hand, is highly dependent on vehicle type. In the analyses here “Honda Civic” is selected as the representative car type.[4] The data used for the estimation of depreciation function is obtained from Kelley Blue Book website (www.kbb.com).[5] The prices given in the database for the representative car are correlated with the vehicle age (*a*) and the total kilometers traveled over many years (*m*).

Table 3 Operating Costs (AAMA Report, 1996; USDOT Report, 1991)

Operating	**Costs**
Gas & Oil	0.038
Maintenance	0.018
Tires	0.009($/kilo
Insurance	1,350
Parking and	0.0113

* 2000 dollars

Marginal vehicle operating cost is a function of **vehicle age** only.[6] Since it is not possible to identify the age of every single vehicle in the network, an average value of 8.5 years as reported in the AAMA’s report has been employed here (AAMA Annual Report 1996).

3.2. Congestion costs

Congestion cost defined here 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 O-D 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. In order to calculate congestion costs, an average value of time (VOT) (in dollar per hour) has been employed. The value ranges between 40% and 170% of the average hourly wage rate in NJ. This range enables a better understanding of FMC within a range of VOT assumptions.

The Bureau of Public Roads travel time function was used to calculate time loss[7]. Thus, total cost of congestion between a given *O-D* pair (*r*, *s*) 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).

Table 2 presents the marginal congestion cost, which is simply the first order derivative of the total congestion function with respect to traffic volume (*Q*). The first component on the right hand side of this function is the cost directly experienced by a user, and the second is the cost imposed on other users by an additional vehicle on the route.

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[4] It should be noted that the same analysis is performed for other high selling car makes and the resulting depreciation functions are quite close for each car make.

[5] Our estimation includes trade-in values only.

[6] This is because the estimated vehicle operating cost is a linear function of the variable “total kilometers traveled (m)” and the first order derivation of the factors out the variable *m*.

3.3. Accident costs

Accidents are non-recurrent events, in other words it is impossible to know with certainty when or where a particular accident will take place. In order to calculate accident costs, the necessary information required is the *accident occurrence rate*. This is defined as the number of a specific type of accident that has taken place over a given period of time in given location. In this study, accidents are categorized as **fatality**, **injury** and **property damage** accidents. Accident occurrence rate functions for each accident type were then developed.

Historical data obtained from NJDOT shows that annual accident rates for each accident type are closely related to **intensity of traffic volume** and **roadway geometry**.

Intensity of traffic volume can be included in the accident occurrence rate function using **average daily traffic volume** and **road length** as the model's variables.

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, such as number of lanes, vertical and horizontal alignments, super-elevation, coefficient of friction, sight obstructions, stopping sight distances, etc. However, these variables are detailed to be considered in a given function. Thus, to consider the effects of roadway geometric design in the accident occurrence rate function, highways have been classified on the basis of their functional type, namely **Interstate**, **Freeway-Expressway** and **Local-Arterial-Collector.** It is assumed that each highway type has its unique roadway design features

Therefore, accidents are classified based on the highway functional type where the accident took place. This qualitative classification provides the convenience of working with only two variables: **average daily traffic volume** and **road length**[8]. With the qualitative classification of roadway design, there are 3 accident occurrence rate functions for each accident type for each of the 3 highway functional type. Hence, nine different functions need to be developed in total. Regression analyses have been used to estimate these functions. The available data consist of a detailed accident summary for the years 1991 to 1995 in New Jersey. For each highway functional type, the number of accidents in a given year by is reported. The statistical results of accident occurrence rate estimation can be found in Ozbay et al. (2000).

Multiplying accident occurrence rate for each accident type by the unit cost of the respective accident type yields the total accident cost over a given period of time. Unit cost of each accident type is taken from Miller (93) and is given in Table 4. Table 2 presents the marginal accident cost functions for each highway functional type.

3.4. Infrastructure costs

Infrastructure costs include all long-term expenditures, such as land acquisition costs; cost of facility construction, material labor and administration costs, regular and unexpected maintenance expenses. These costs are also subject to an interest rate over the lifetime of the facility.

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[7] We also tried an up-to-date travel time function. However, as presented in Ozbay et al (2000), other travel time functions quickly gets very high values as volume to capacity ratios increase. This fact results in unrealistic travel time costs.

[8] This approach is also consistent with previous studies e.g., Mayeres et al. (1996)

Infrastructure costs are categorizes as **new construction costs**, **maintenance and improvement costs**, and **right-of-way costs** (land acquisition costs). The data employed for the estimation of the infrastructure cost function include all type of new construction works, maintenance and improvement works completed between 1991-1998 in NJ, and the right-of-way data for the last 20 years.

Table 4 Accident Costs by type

Accident Type	**Cost per Accident ($)**
Fatality	4,113,956
Injury	144,291
Property Damage	6,783

(**Source**: Miller (93). The unit cost values are converted to 2000 dollars assuming a 3.5% inflation rate)

Following a regression analysis, it is observed that in the short run new construction and right-of-way costs are not a function of traffic volume (*Q*). This is due to the lack of required data on the relationship between expected traffic volume and capital expenditures [9]. Thus, these categories cancel out in the final marginal cost formula.

Maintenance and improvement costs are divided into three subcategories due to the excessive variety of work types found in the NJDOT's database. These are (1) Major reconstruction with/without roadway widening, (2) roadway widening with/without resurfacing, and (3) resurfacing with/without minor roadway widening.

The cost functions estimated for these maintenance and improvement work types provide estimates for the cost of each type of roadway maintenance projects. However, the functions are to be used on a "per project" basis. To utilize these cost functions, we need to know how often each type of maintenance work is undertaken given the traffic conditions and pavement characteristics. There are established methods for estimating resurfacing cycles (Small et al., 1989); however, there are no known practical methods for estimating the cycle of other maintenance work categories. It is known that the first two maintenance and improvement categories are undertaken when the highway link becomes no longer adequate for carrying the traffic. However, this analysis requires a transportation demand model, which is out of the scope of this paper. Therefore, the first two cost categories are excluded from the marginal cost analysis (Ozbay et al, 2000).

Table 2 shows the marginal infrastructure cost function used in this study.

3.5. Environmental costs

Environmental costs due to highway transportation are categorized as **Air Pollution** and **Noise costs**.

3.5.1. Air Pollution Costs

The consequences of air pollution are pervasive and far-reaching, and it is complex to track of its effects. Detailed and meticulous research is essential to formulate a reliable air

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[9] Readers may refer to Ozbay et al. (2000) for the estimated cost functions for New Construction and Right-of-Way expenditures.

pollution cost function, which is not within the scope of this study. Therefore, findings from literature have been adopted to formulate an air pollution cost function specific to NJ. Air pollution costs are estimated by multiplying the amount of pollutant emitted from vehicles by the unit cost values of each pollutant. We consider the major pollutants including volatile organic compounds (*VOC*), carbon monoxide (*CO*), nitrogen oxides (NO_x) as directly emitted pollutants, and particulate matters (PM_{10}) as indirectly generated pollutant. Detailed explanation of the formulization of the air pollution cost function is given in Ozbay et al. (2000). The following steps summarize this process:

1. First, we have adopted a fuel consumption function (Ardekani et al. 1992). This function calculates the fuel burnt in liters per kilometer based on an average vehicle speed.
2. Second, the emission rate of pollutants is calculated (*grams/liters*).
3. Third, the amount of pollutant is multiplied by its unit cost to calculate the air pollution cost caused by one vehicle.

Unit cost values of each pollutant is shown in Table 5. Multiplying the cost per user by the traffic volume yields the total air pollution cost per kilometer over a period of time. The first order derivative of this function yields the marginal air pollution cost function (See Table 2).

Air pollution costs considered in this study comprise only local effects. However, it is commonly known that air pollution can be trans-boundary or even global. The further its effects are explored the harder it becomes to measure its monetary cause. However, even the measurable costs of air pollution are high enough to justify the substantial expenditures to control vehicle emission rates (Small et al. 1995).

Table 5 Cost of each pollutant type (2000 dollars)*

	VOC	**NO_x**	**CO**	**PM_{10}**
Unit Morbidity Cost per ton	$ 1,676	$ 3,039	n/a	$ 6,542
Unit Mortality Cost per ton	$ 2,779	$ 7,320	$ 15.21	$ 126,074
Total Unit Cost per ton	**$ 4,455**	**$ 10,349**	**$ 15.21**	**$ 132,616**

*Morbidity costs are taken from Small and Kazimi (1995)

3.5.2. Noise Costs

The costs of noise externalities are most commonly estimated as the depreciation in the value of residential units alongside the highways. Presumably, the closer a house to the highway the more its value will depreciate. While there are other factors that cause depreciation in housing values, “closeness” is utilized as the major variable explaining the costs from noise externality. The Noise Depreciation Sensitivity Index (*NDSI*) as given in Nelson (1982) is defined as the ratio of the percentage reduction in housing value due from a unit change in the noise level. Nelson (1982) suggests the value of *0.40*% for *NDSI*. The amount of depreciation is defined as:

$$ND = N_h \cdot (L - L_{\max}) \cdot D \cdot W_{avg} \tag{5}$$

Where,

ND = Depreciation due to noise,

N_h = Number of affected houses per km^2. N_h is calculated by multiplying the **average residential density** (RD) in the neighborhood of the highway by the **distance to the highway** (r) and the **length of the highway section** (d)[10], i.e.,

$$N_h = 2 \cdot RD \cdot r \cdot d \qquad (6)$$

L = Equivalent Noise Level (dB(A)), $L = f(Q, V, d)$, where Q is traffic flow, V is the average traffic speed and d is the distance to the highway. Its function is adopted from Galloway et al. (1969),

$L_{\max}$ = Maximum acceptable noise level (dB(A)),

D =Percentage discount in value per an increase in the ambient noise level (*0.40* %),

W_{avg} = Average house value (*$*). (See Table 6 below),

$L_{\max}$ can be defined threshold of annoyance. Any sound louder than this value is perceived as a disturbing sound. This value is assumed to be *50* (dB(A)), which corresponds to normal conversational speech level.

Table 6 Housing Value in NJ

Value Range	*$*
Lower Value Quartile	158,410
Median Value	228,940
Upper Value Quartile	317,385

What equation (5) actually says is that whenever the ambient noise level at a certain distance from the highway exceeds $L_{\max}$, it causes a reduction in the value of houses that fall within this distance. Thus, the noise cost depends both on the **noise level** and on the **house value**. Applying equation (4) for a range of 1-km highway segment, we can calculate the total noise cost over many years. The marginal noise cost function is given in Table 2.

It should be noted that noise costs are highly sensitive to assumptions. For different W_{avg}, D, RD values, the resulting noise cost will have different values[11].

4. Results

For one-route marginal cost (*ORMC*) estimations, we selected one origin in each county in Northern NJ. *ORMC* values are calculated for the shortest routes between these selected O-D pairs. In this process, we employed the marginal cost functions developed for each cost category as presented in Section 3. The generalized cost formula used in *ORMC* calculations is given below[12].

$$ORMC_{r,s} = \sum_{i=1}^{k} FMC^{i} = \sum_{i=1}^{k} MC^{i}{}_{opr}.d + MC^{i}{}_{cong} + MC^{i}{}_{acc} + MC^{i}{}_{\inf} + MC^{i}{}_{air} + MC^{i}{}_{noise} \qquad (7)$$

Where,

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[10] The multiplication by 2 in equation (5) is used to calculate the number of housing units on each side of the roadway.

[11] For details, see Ozbay et al. (2000).

[12] The units of noise and air pollution costs are given as $/trip here. However, it should be noted that in our analyses for each O-D pair in the network, their respective units have been utilized according to the trip characteristics.

FMC: Full Marginal Cost ($/mile)
MC_{opr}: Marginal vehicle operating cost ($/trip),
MC_{cong}: Marginal Congestion cost ($/trip),
MC_{acc}: Marginal Accident cost ($/trip),
MC_{inf}: Marginal Infrastructure cost ($/trip)
MC_{air}: Marginal Air pollution cost ($/trip)
MC_{noise}: Marginal Noise Cost ($/trip)
(r, s): Origin-Destination pair
k: Number of links between origin destination pairs, on the shortest route.
d: Trip distance (miles)

In total, we have *18,850 ORMC* values with their corresponding attributes. As mentioned in Section 3.2, *ORMC* values have a cost range based on the value of time (VOT) assumptions. We assumed a VOT range of *40%-170%* of the average hourly wage in NJ. This enables us to better estimate full marginal cost under various time values. The analysis is also repeated for off-peak period to observe the difference in the marginal cost values.

In Figure 2, *ORMC* values are plotted with respect to trip distance for both peak and off-peak hours, assuming a VOT of $*7.6*/hr. As expected, peak-hour values are greater than off-peak hour values, and the difference becomes significant as trip distance increases. Thus, the addition of longer trips due to urban sprawl can be expected to have increasingly higher impacts in terms of *FMC*. Figure 3 shows *ORMC* distribution with respect to trip distance when VOT is equal to $*32.3*, which is assumed an upper bound. It is clear that the difference in *ORMC* values for peak and off-peak hours are greater than those of Figure 2. This result can be supported by the fact that congestion cost is more sensitive to VOT assumptions during peak hours than to VOT values at off-peak hours. Moreover, congestion costs appear to be the major driving component of the overall costs. Thus, it is important to emphasize the effects of congestion reduction measures in terms of overall costs.

In order to observe the effect of highway functional type and urbanization degree on *ORMC* values, we need to hold trip distances as constant. We assume that for the same trip distance, the difference in *ORMC* values is attributed solely to highway functional type (interstate-freeway-expressway, principal arterial, minor arterial and local-collector) and degree of urbanization.

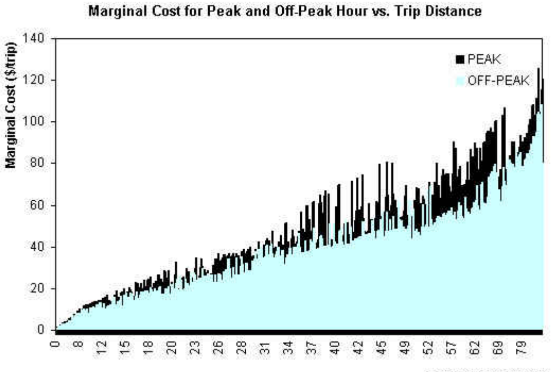


Figure 2 *ORMC* Distribution with respect to trip distance for peak and off-peak hours (VOT=$7.6)

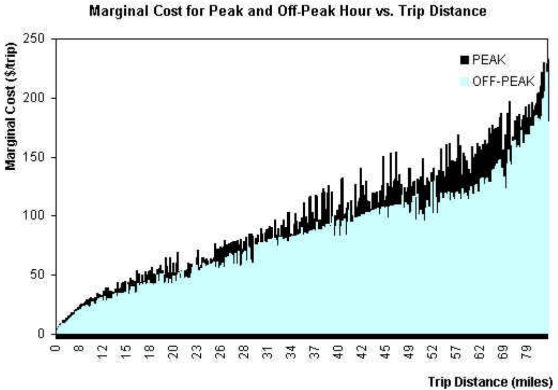


Figure 3 *ORMC* Distribution with respect to trip distance for peak and off-peak hours (VOT=$32.3)

First, we analyze the effect of highway functional type on *ORMC* value for a given trip distance. The analysis shows that the change in *ORMC* values with respect to highway functional type does not have a general pattern, which is irrespective of trip distances. Thus, we examine this relationship for different trip distance ranges. For relatively short distances (i.e. 0-10 miles) the routes that have a higher percentage of local-collector highways on a given route, tend to have smaller *ORMC* values.

Figure 3 and 4 depict the effect of local-collector percentage of the shortest routes on *ORMC* values during peak and off-peak hours for trip distance of 2 miles. It is seen that during peak and off-peak hours, as the local-collector highway type percentage increases, *ORMC* value decreases in general. The same patterns that are obtained in Figures 3 and 4 hold for trip distances only up to 10 miles.

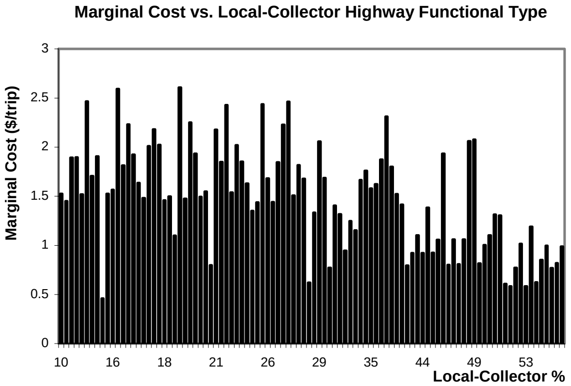


Figure 3 ORMC Distribution with respect to highway functional type percentage during peak hours for 2-mile trip distance (VOT=$7.6)

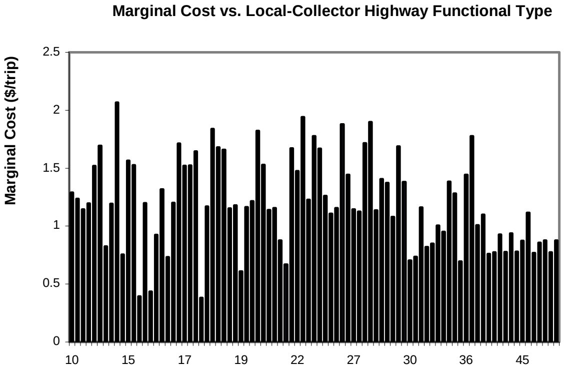
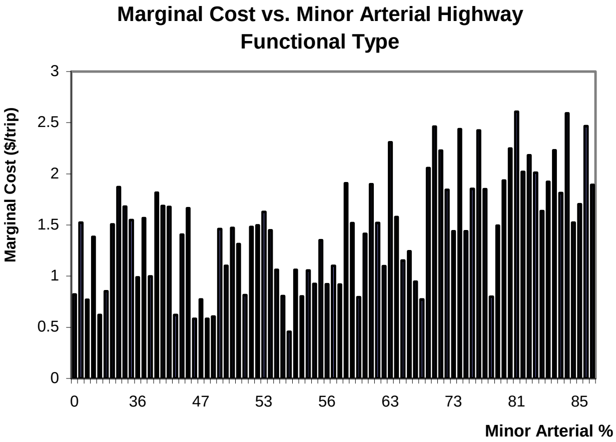


Figure 4 ORMC Distribution with respect to highway functional type percentage during off-peak hours for 2-mile trip distance (VOT=$7.6)

Figure 5 and 6 depict the variation of *ORMC* with respect to minor arterial highway functional type percentage for a trip distance of 2 miles. Unlike local-collector highways it is observed that as the percentage of minor arterial highway of a route increases, *ORMC* value slightly increases as well. However, *ORMC* distribution with respect to minor arterial road percentage as shown in Figure 5 and 6 holds for trip distances up to 3 miles. For trip lengths between 3 and 10 miles, *ORMC* values tend to decrease as minor arterial percentage increases.



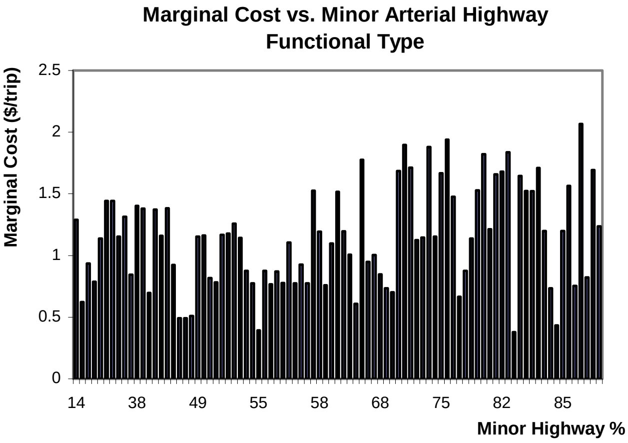


Figure 5 ORMC Distribution with respect to highway functional type percentage during peak hours for 2-mile trip distance (VOT=$7.6)

Figure 6 ORMC Distribution with respect to highway functional type percentage during off-peak hours for 2-mile trip distance (VOT=$7.6)

Since short trips do not generally use interstate-freeways-expressways, the effects of this highway functional category on *ORMC* distribution cannot be accurately analyzed for these short trip distances. As for principal arterials, sufficient information can be gathered for trip distances longer than 3 miles. In Figure 7, it is shown that within the same trip distance range (3-10 miles), *ORMC* value slightly increases with increasing principal arterial percentage for a given route.

The reason why *ORMC* distribution patterns change within 0-10 mile range is that, as trip distance increases, the percentages of each highway functional type changes as well. That is, up to 3 miles, the road types used are mainly local-collectors and minor arterials. It is obvious that local roads are more convenient than minor arterials for shorter trips. Above 3 miles, the utilization of principal arterials becomes significant; and *ORMC* value increases due to more congestion along these routes. Finally, beyond 10 miles, minor arterial and local-collector type of highways are not as significantly utilized as interstate-freeway-expressways and principal arterials.

Next, we analyze *ORMC* distribution with respect to the percentage of highway functional type for longer trips distances. In this section, we only present the analysis performed for 25-miles trip distance. However it should be noted that similar patterns are observed for all trip distances longer than 10 miles.

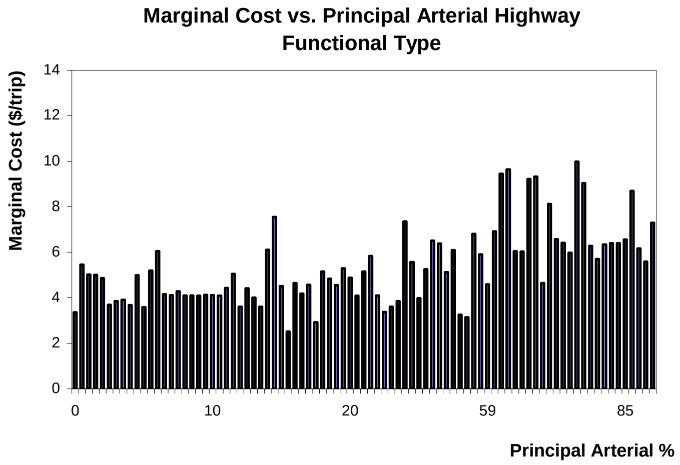
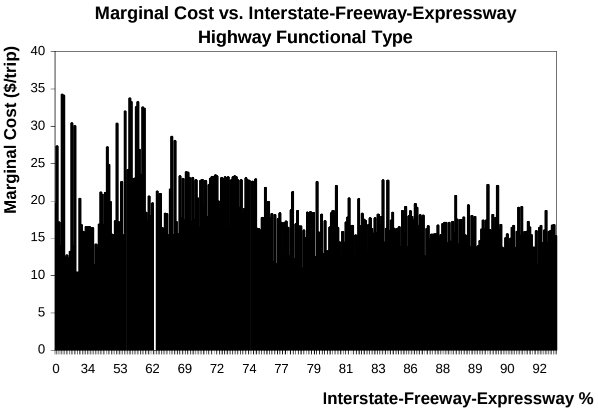


Figure 7 ORMC Distribution with respect to highway functional type percentage during peak hours for 7-mile trip distance (VOT=$7.6)

Figure 8 depicts the *ORMC* distribution with respect to interstate-freeway-expressway percentages for peak period. It is seen that *ORMC* values tend to decrease as interstate-freeway-expressway percentage increases. The same pattern holds during off-peak periods as well. Figure 9 depicts *ORMC* distribution with respect to principal arterial percentage. It is seen that the same pattern we get in Figure 8 is still valid for 25-mile trip range. As the trip distance becomes more than approximately 50 miles, interstate-freeway-expressway comprises most of the route distance. This fact restricts the analyses of *ORMC* distribution with respect to principal arterial as well as to interstate-freeway-expressway percentage.



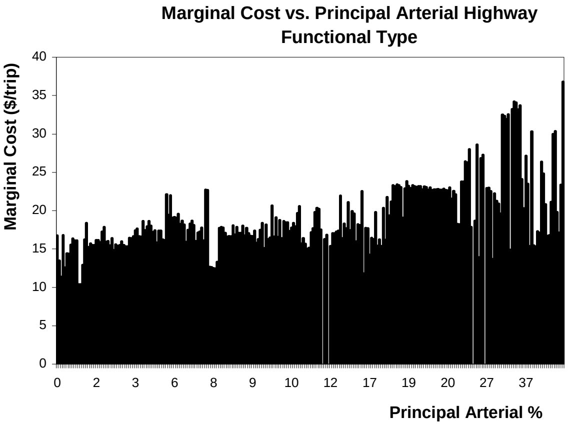


Figure 8 ORMC Distribution with respect to highway functional type percentage during peak hours for 25-mile trip distance (VOT=$7.6)

Figure 9 ORMC Distribution with respect to highway functional type percentage during peak hours for 25-mile trip distance (VOT=$7.6)

Finally, we attempt to correlate the variation in *ORMC* values and urbanization degree using the data generated. Figure 10 depicts the *ORMC* variation with respect to urbanization percentage over a given trip distance. Similar analyses are done for all the trip distance ranges both for peak and off-peak periods. However, *ORMC* variations with respect to urbanization degree do not follow a typical pattern. Thus, we can conclude that urbanization degree around highways does not necessarily imply an increasing congestion level.

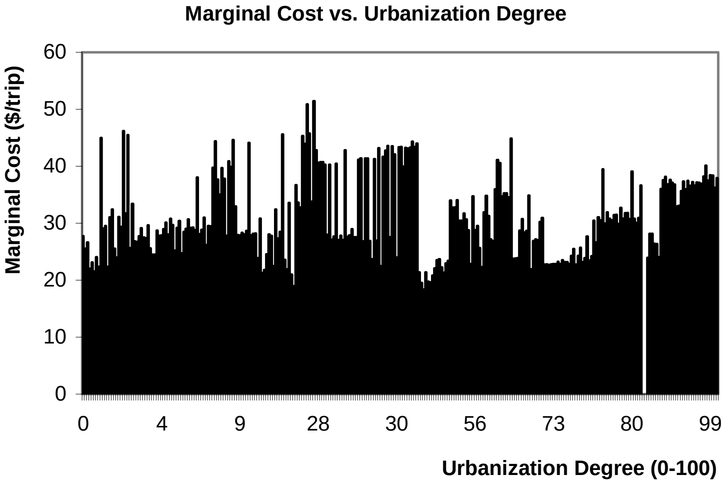


Figure 10

ORMC Distribution with respect to urbanization degree during peak hours for 40 miles trip distance (VOT=$7.6)

5. Evaluation of the current pricing policy

Knowing the full marginal cost of highway transportation can be of vital importance due to the ongoing efforts to reduce congestion, through the use of congestion tolls. Leaving aside the practical difficulties and political complexities of this concept, we would like to evaluate the efficiency of the current practice of collecting highway user fees in New Jersey relative to the results obtained above.

Highway marginal cost pricing requires that every user should be held responsible for the cost he or she imposes on the rest of the traffic due to his/her additional trips. Hence, in theory, user fee per trip should be equal to the external cost of a trip (Small, 1992). Therefore, if we compare the value of the actual user fees per trip currently imposed in New Jersey with our estimate externalities through the *FMC* methodology, we could measure the effectiveness of highway pricing policies in New Jersey.

It is known that average congestion cost and vehicle operating costs are fully experienced by the users. Infrastructure and maintenance costs, on the other hand, are paid through fuel and vehicle registration and other taxes. Hence, we need to determine if the user fees collected by the government are sufficient enough to cover the "external" costs of highway transportation, such as increased travel time, pollution and accidents. It is known that a certain portion of congestion and accident costs are external, meaning that it is directly imposed on the rest of the traffic by an additional trip. In our analysis here, we have calculated the congestion externalities. As for accident externalities, we have adopted a ratio of marginal to average accident cost of 1.52 in our analyses (Newberry, D., 1988). Finally, we consider air pollution and noise costs as external costs to the rest of the traffic and the society.

However, the detailed analysis of this task is not straightforward as trips have several quantitative and qualitative measures that cannot be grouped together easily. Consider for example, the difference between a 50-miles trip and a 3-miles trip, or two trips with the same distance but on different highway types, etc. Therefore, there is not a unique value for *FMC* per trip. For our analysis here, we have used the average of all *ORMC* values within a trip distance that range of 10-15 miles[13] and weighted the averages for peak and off-peak hours. The average *FMC* values by each cost category are presented in Table 7. It should be noted that the contributions of each cost category to *FMC* as shown in Table 7 is not unique for all trip distance ranges; however, we believe that Table 7 provides a good idea of each cost category's contributions.

Using the air pollution, noise costs, congestion externalities, and a ratio of marginal to average accident cost of 1.52 for accident externalities suggested by Newberry (1988), we calculate the external cost of making a trip within a distance range of 10-15 miles as $1.252.

Table 7 Full Marginal Cost by categories for a trip distance range of 9-15 miles.

Operating Cost ($)	**Congestion Cost** ($)	**Congestion Externality**	**Accident*** **Cost** ($)	**Infrastructure Cost** ($)	**Air Pollution Cost** ($)	**Noise Cost** ($)
1.389	3.786	0.635	1.009	0.062	0.114	0.158

* Accident externality= Marginal Accident Cost- Average Accident Cost = 1.009-(1.009/1.52)=0.345

We now need to find out if the cost imposed by the government is equal to our *FMC* estimates. FHWA reports that an amount of $2,703,741,000 for New Jersey was collected through federal and state fuel and vehicle tax, state and local tolls in 1998 as highway user revenues (FHWA Report, Highway Statistics Series, 1999). Dividing this amount by the annual total number of trips taken in New Jersey in 1998, 6.31 billion, we get an estimate of the cost of a trip in New Jersey as $0.428 (NJDOT Transportation Fact Book, 2000)[14]. This is the amount that the government charges, on the average, each user per trip. Comparing this amount with our *FMC*, we observe that it is less than what we regard as necessary amount to compensate for the full marginal cost per trip.

What then should be the right amount of increase in user fees that should be imposed on users to compensate for the marginal roadway pricing in NJ? Let us assume that $1.252 is the user fee per trip that the state government targets. Let us also assume that the state government decides to collect the deficit of user fees only by "state fuel tax". The annual user revenue that should be collected becomes $1.252 x 6.4386 billion trips (see footnote 14), which is equal to $8,061,127,200. Assuming the federal vehicle and fuel tax revenues,

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[13] National Personal Travel Summary Survey Summary (1995) reports an annual national average vehicle trip length of 9.06 miles. A value specific to NJ is not available. Thus we have chosen a range of 9-15 miles trip length.

[14] The number of trips reported in 2000 is converted to 1998 values assuming a 2% increase per year in the total number of trips.

$962,433,000, and state and local tolls revenues, $619,862,000, remain the same, the dollar amount that the state needs to collect is now $8,061,127,200- ($962,433,000 + $619,862,000) = $6,478,832,200. This is the amount that needs to be raised by state vehicle and fuel taxes. FHWA reported that vehicle tax collected in 1999 was $631,506,000. Hence $6,317,609,656- $631,506,000 = $5,847,326,200 would be the total amount that the state government needs to collect by state fuel tax only (FHWA Report, 1999). Dividing this amount by the taxable amount of fuel consumed in New Jersey in 1999, 4,688,147,000 gallons, would be equivalent to the new additional state fuel tax, which comes out to be $1.247 per gallon (FHWA Report, 1999). This additional amount is far more than the current state fuel tax of $0.1038 per gallon[15]. Although the collection of this revenue through the gas tax only is not an impossible task, it does not appear to be an easy policy to sell to the American people. Table 8 presents the fuel tax charged in different countries in Europe as a percentage of the fuel price. As seen, the current fuel tax in US is far less than European countries. Even our estimated fuel tax percentage is less than the values in effect in European countries.

Table 8 Fuel Prices and Percent Taxes in European Countries

Country	*Percent*	*Tax*	*Price per*
United	76.8 %	3.295	$4.29
Netherlands	68.4	2.708	$3.96
France	72.7	2.661	$3.66
Italy	67.7	2.464	$3.64
Germany	70.7	2.418	$3.42
USA	24.1	0.419	$1.74
USA	47.3		$3.303

* Gas tax as a percentage of retail price of gallon of gas

** Retail price per gallon of premium leaded as of September 11, 2000.

***Tax amount includes the federal tax plus our recommended state fuel tax, $1.247, instead of the current state fuel tax of $0.1038/gallon.

Source: *The Detroit News* (9/20/2000). **Original Source**: International Energy Source, National Energy Information Center

6. Conclusions

In this study, a new methodology for estimating network–wide Full Marginal Costs is presented. This methodology is applied to determine the full marginal cost of highway transportation in Northern NJ. The variation in marginal cost value due to trip distance, degree of urbanization and highway functional type, are analyzed. Each set of observations is done for different VOT assumptions, and time periods (peak and off-peak hours).

The following are our main conclusions:

1. The difference in the marginal cost value for peak and off-peak hours become more significant with the longer trip distances due to the increase in congestion costs.
2. Marginal costs are estimated to reduce as the percentage of the trip-distance that includes freeway and expressways increases.

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[15] This value is the weighted average of all fuel tax rates based on the taxable amount in 1999.

3. It is observed that along the routes that have a higher percentage of principal arterials, marginal costs tend to increase.
4. It is concluded that urbanization around the highways has no significant effect on the marginal costs.
5. We also used our full marginal cost findings to evaluate the current pricing policy. It is observed that the government's highway user revenue is far below than the amount that is required to meet the marginal roadway-pricing criterion.

It should be noted the results presented here are specific to NJ area. Furthermore, the marginal cost values estimated are sensitive to other assumptions that are not included in this study. For example, travel time function used to calculate congestion costs could affect marginal cost values significantly. The Bureau of Public Road's (BPR) travel time function is utilized in this study. The variation in the cost values can be observed using different travel time functions.

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