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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 the northern New Jersey highway network. We review the existing studies and identify the highway transportation cost categories. Cost functions are developed using New Jersey-specific data for each cost category. Along with the total cost functions, marginal costs functions are derived. 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.

INTRODUCTION

There is a growing interest among transportation agencies in determining the full cost of transportation services for both short- and long-term planning purposes. The main objective behind this interest is to ensure prices paid by transportation users correctly reflect the true costs of providing transportation services. Economists argue that "getting prices right might not be the end of economic development, but getting prices wrong

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frequently is" (Meier 1983, 1 and 231; Timmer 1987, 39). In the case of transportation, optimal user charges should be equal to the value of the resources consumed through the use of transportation facilities. For example, for road users prices charged should consist of the damage done to the road surface (variable road maintenance costs) and the additional costs (mainly congestion costs) each user imposes on other users and the rest of society (Walters 1968; Churchill 1972). Thus, it is extremely important to accurately estimate the full cost of various modes of transportation for a given study area in order to develop effective long-term transportation pricing schemes.

This paper is mainly concerned with the estimation of the full marginal costs of highway transportation in New Jersey and the analysis of these cost models through their application to a northern New Jersey network. By "full marginal costs" we mean the full social costs of transporting an additional trip-maker over the highway network system. This information is mandatory for the development of an efficient transportation pricing scheme.

This paper has two major objectives.

1. To develop a general cost model to estimate the full costs of highway passenger transportation using New Jersey-specific data.
2. To apply this cost model to the northern New Jersey 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 New Jersey transportation system. In the final section, we present a comparison of the costs we estimate and the user revenue collected by the government, reflecting the efficiency of the roadway pricing in New Jersey.

The full measure of highway transportation costs are usually categorized as "direct" and "indirect" costs. Direct costs, sometimes called "private" or "internal costs," include the costs auto users directly consider monetary losses, such as vehicle operating cost, car depreciation, time lost in traffic, infrastructure cost (through taxes), and so forth. Indirect costs, also called "social" or "external costs," refer to the costs auto users are not held accountable for, including those every user imposes on the rest of traffic, such as the costs of congestion, accidents, air pollution, and noise. An extensive literature review yielded the cost categories and data sources shown in table 1.

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

The importance of focusing on the marginal costs of service provision in a given area stems from the fact that marginal costs measure the actual increase in costs from an additional mile (or trip) traveled. Thus, marginal costs represent the additional costs the state should consider when encouraging efficient transportation use. Although traditional government cost allocation studies have gradually incorporated concepts similar to marginal costing, non-governmental costs are still largely ignored. However, the costs of congestion, pollution, and accidents are real costs to the government as well as to society. In brief, a marginal cost approach that includes practically measurable external costs tends to be more realistic.

PROPOSED MARGINAL COST ESTIMATION METHODOLOGY

In this paper we consider a common situation: the marginal cost of highway travel is higher than the average cost, reflecting the fact that an additional vehicle in traffic imposes a definite cost on all users (Mohring 1976). Figure 1 demonstrates this specific case. Due to the lack of a pricing policy that sets the price to users equal to full marginal costs (*FMC*), highway transportation infrastructures are over utilized, auto and truck users do not pay for what they consume, and the cost to society of serv-

TABLE 1 Major Cost Categories and Data Sources

Cost categories	Payer	Data sources
Vehicle operating cost ■ 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 and improvements ■ Right-of-way	Public	NJDOT
Environmental costs ■ Air pollution ■ Noise	Public and private	Existing studies and NJDOT, U.S. Environmental Protection Agency (USEPA)
Congestion costs ■ Travel time	Private	NJDOT
Accident and safety costs ■ Bodily and property damage ■ Productivity ■ Emergency and medical services (police + ambulance + rescue)	Public and private	NJDOT

ing an additional trip is higher than the average cost at that demand level[1] (see point *A* in figure 1).

The formulation of the *FMC* involves the cost of making a trip between origin-destination (O-D) pairs in a network, which is a function of several variables, here denoted by V_j. The average cost, C_{rs}, of one trip between a specific O-D pair (*r, s*) follows:

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

where, q denotes the demand between the O-D pair. We assume that there are q homogeneous users who make the same trip over a given time period.[2] The full total cost (*FTC*) of providing a transportation service between any O-D pair for q trips is defined as follows:

$$FTC_{rs} = qC_{rs} = qF\left(V_j ; q\right) \tag{2}$$

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

[2] The term "user" here connotes a vehicle-trip.

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

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

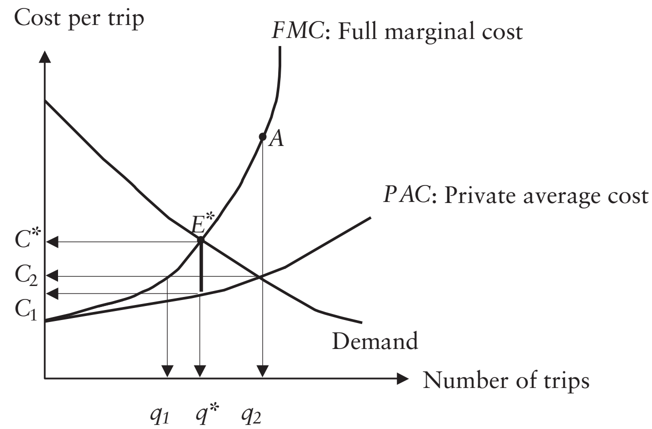
This function gives the cost of adding an extra trip to the system. The first term represents the average cost, and the second term represents the additional cost of a trip. Thus, if we add one more user making an extra trip, the cost imposed by an additional trip to the rest of the traffic is $q\left(\partial F\left(V_j ; q\right) / \partial q\right)$. 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

$$FMC\ (\$) = \text{private average cost } (\$) + \text{congestion-related costs } (\$)$$

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

FIGURE 1 Hypothetical Marginal and Average Costs of Highway Transportation



q^* = Number of trips at social equilibrium
C^* = Cost per trip at social equilibrium
C_1 = Private cost per trip at social equilibrium
C_2 = Private cost per trip at private equilibrium
q_2 = Number of trips at private equilibrium

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)

$$TR = \left(\frac{\partial FTC(q^*)}{\partial q}\right) q^* = \frac{1}{s} FTC \qquad (4)$$

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 $s \leq 1$ (where $s = AC/MC$ and *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.

Estimation and Analysis of Network-Wide Full Marginal Costs

As discussed, full marginal costs is defined as the total costs accrued to society from an additional unit of travel, that is, an additional user. Although highway transportation might seem to be the production of a single output in a highway network, the reality is more complicated, in part because users make decisions within the network to minimize their own costs. They change their routes and times of travel constantly, based on network attributes, such as travel demand, number of routes between O-D pairs, capacity of each link, and so forth. Hence, if we introduce an additional demand between a selected O-D pair, not only do the travel patterns on each route connecting that O-D pair change, but the travel patterns on every route in the network will also change.

In multiple origin-destination and multiple-route networks, the practical and operation calculation of the network-wide marginal cost is complicated by the following issues.

- Do we add an extra demand unit between every O-D pair or do we pick one O-D pair and add the extra unit of demand to this pair? If so, which O-D pair do we select?
- What is the effect of this extra unit of demand on the overall network equilibrium? Does the addition of one extra unit flow (a vehicle) to a large network affect the overall equilibrium condition?

To address these issues in our proposed network-wide full marginal cost estimation methodology, we assume that the additional flow in the system does not disturb the existing flow patterns in the network.[3] We then propose adding this additional

[3] Jara-Diaz et al. (1992) has introduced the idea of network-wide marginal costs in the context of a freight network in Chile.

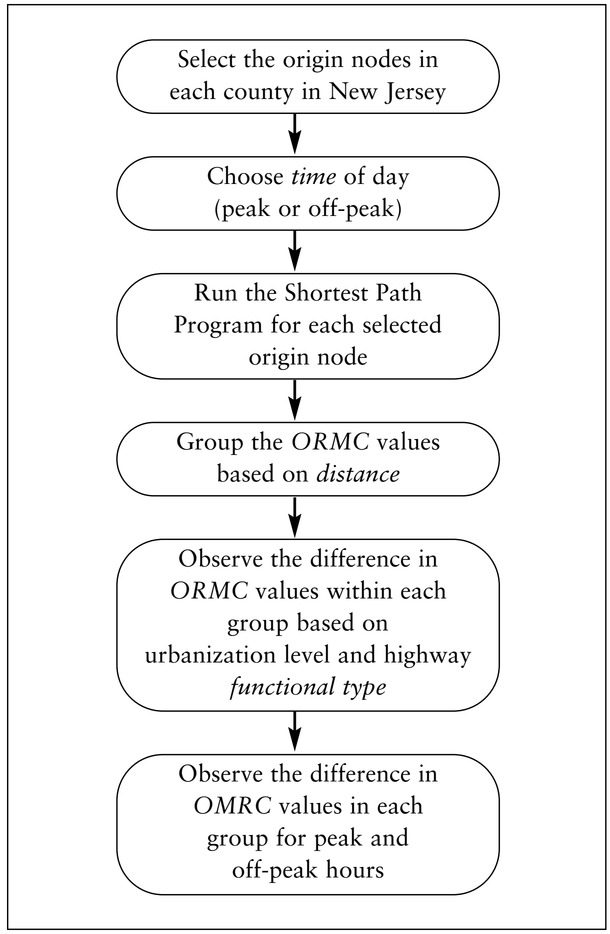
trip between a selected O-D pair onto the shortest route between this specific O-D pair and calculating the marginal cost for this trip. We call this marginal cost one-route marginal cost (*ORMC*). We are aware of the fact that the resulting value will not be the same as the true system-wide marginal cost. This value can only be obtained by performing a new traffic equilibrium assignment, which will reflect the change in flow patterns due to the addition of an extra unit of demand. However, compared to the overall demand, because the additional demand is relatively small (a single trip between a given O-D pair, we can assume that the resulting costs will be reasonable approximations of actual costs. A detailed explanation of the theoretical implications of this marginal cost estimation procedure is given in Ozbay et al. (2000).

To estimate network-wide marginal costs in the northern New Jersey network, we first determine marginal costs along the shortest routes for each individual O-D pair in the network. We then group the O-D pairs according to several quantitative and qualitative factors similar to the ones listed in Jara-Diaz et al. (1992). For each O-D pair, these factors include 1) level and variance of demand flow, 2) traffic conditions, and 3) factors induced by movements between other O-D pairs. Additionally, some physical factors relate to the O-D pair: 1) topography, 2) climate, and 3) characteristics of the corresponding right-of-way. For practical reasons, Jara-Diaz et al. (1992) does not include all of these factors in the marginal cost function. Instead the authors group the observations based on the qualitative factors. They also develop separate marginal cost functions for each category. In this analysis, we follow a similar approach. Given data availability, the factors considered in this study are

- Distance between O-D pairs
- Functional type (percentage of highway functional types on the shortest routes between O-D pairs, such as interstate, freeway, arterial, and so forth)
- Residential density of the areas where the shortest routes are located (central business district, urban, suburban, or rural)
- Time of the day (peak hours or off-peak hours).

Figure 2 depicts the process of calculating *ORMC* for several O-D pairs, grouping them according to

FIGURE 2 *ORMC* Calculation Process



the factors listed above for the northern New Jersey highway network link volumes provided by the New Jersey Department of Transportation (NJDOT).

The northern New Jersey network used in this process consists of 5,418 nodes, 1,451 of which are zonal,[4] and a total of 15,387 links. Shortest routes between zones are determined using a computer program developed in Avenue,[5] based on Pape and Moore's shortest path algorithm (Pape 1974). Every time the shortest route between an O-D pair is determined, desired link properties (such as distance, functional type of the highway, residential density, travel time, county name, and traffic volume) are extracted by the program. As for the time of the day, we use peak and off-peak loaded networks and perform the analysis for these two time intervals. Figure 2 shows the *ORMC* procedure.

[4] A zonal node means to origin-destination zones where trips originate and end.
[5] Avenue is an object-oriented programming language used to create user interface for ArcView GIS.

DEFINITION AND FORMULATION OF COST FUNCTIONS

In this study, we have reclassified highway transportation costs into three major categories: user costs, infrastructure costs, and environmental costs. We develop the total and marginal cost functions for each category using New Jersey-specific data.

User Costs

User costs are put into two major groups: 1) self-vehicle operating costs, that is, car ownership, fuel and oil consumption, regular or unexpected maintenance, and so forth and 2) user interaction costs, that is, accident- and congestion-related costs.

User interaction costs are difficult to calculate for the following reasons:

- The key unit values, value of time (*VOT*) and value of life-injury, are mostly based on the judgment of highway users
- Accident- and congestion-related costs are interrelated and affect all auto users. For instance, at first glance an accident seems to incur costs only for the parties involved. However, the resulting delay causes congestion, making for low-speed operating conditions and time loss for other users. Figure 3 shows the various categories of user costs.

The following two subsections present the formulation of marginal user-cost functions, self-vehicle operating costs and user interaction costs.

Self-Vehicle Operating Costs

Self-vehicle operating costs include vehicle depreciation, fuel, oil, tire-wear, insurance, parking fees, tolls, and regular and unexpected maintenance. The general form of an operating cost function follows.

$$C_{opr} = f\left(C_d, C_g, C_o, C_t, C_m, C_I, C_{pt}\right) \quad (5a)$$

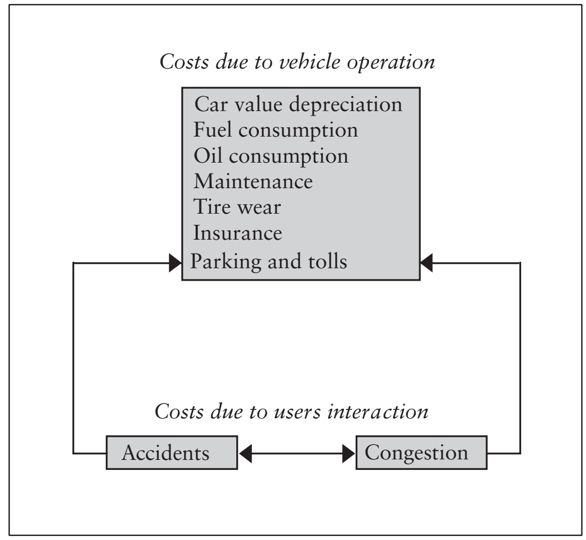
where

C_{opr} is vehicle operating cost over many years (dollars/vehicle)

C_d is depreciation cost for a vehicle over many years

C_g is gas cost (dollars/mile)

FIGURE 3 User Cost Categories



C_o is oil cost (dollars/mile)

C_t is tire cost (dollars/mile)

C_m is maintenance cost (dollars/mile)

C_I is insurance cost (dollars/year)

C_{pt} is parking fees and tolls (dollars/mile).

Depreciation is caused by wear and tear on the vehicle over time and by the change in demand and taste of users. Hence, depreciation cost is assumed to be related to the vehicle's mileage and age. Maintenance, fuel, oil, and tire-wear costs and parking fees and tolls depend mainly on the distance traveled.[6] We used Kelley Blue Book (2000) to estimate our vehicle depreciation cost function. The Honda Civic is taken as the representative car model since it has been the best-selling economy car in the United States for several consecutive years (LTA 1998). The statistical results of this analysis are given in table 2.

Data on insurance costs, parking fees, and tolls are from *Cost of Owning and Operating Automobiles, Vans, and Light Trucks* (USDOT FHWA 1991). Maintenance, oil, and fuel and tire-wear costs are taken from American Automobile Manufacturers Association (AAMA) (1996), in which the cost values are given as national averages and defined on a per mile basis. Table 3 provides a summary of these unit costs.

[6] Here we disregard the effects of traffic, volume, temperature, and altitude on fuel and maintenance costs.

TABLE 2 Results of Regression of Depreciation Cost

Sample size: 217	Coefficients	Value	Standard error	*t*-value	Pr(>|*t*|)	
Intercept	α_0	6,240.3569859	115.0817835	54.2254108	0.00	
m/a	α_1	0.1035028	0.0034358	30.1247472	0.00	
a	α_2	677.7279739	11.9850174	56.5479340	0.00	R_2=0.94

$$C_d = \alpha_0 + \alpha_1 (m / a) + \alpha_2 a$$

TABLE 3 Operating Costs

Operating expenses	Costs*
Gas and oil	0.061 (dollars/mile)
Maintenance	0.029 (dollars/mile)
Tires	0.0145 (dollars/mile)
Insurance	1,350 (dollars/year)
Parking and tolls	0.0182 (dollars/mile)

* 2000 dollars (without tax)

Sources: AAMA (1996), USDOT (1991)

The vehicle operating cost function is developed by combining the values given in tables 2 and 3.

$$C_{opr} = 6{,}240.36 + 0.104 \frac{m}{a} + 2{,}027.73a + 0.1227m \quad (5b)$$

where C_{opr} is vehicle operating cost (dollars/vehicle over many years)
m is the vehicle mileage (miles)
a is the vehicle age (years).

The regression analysis results given in table 2 indicate a depreciation cost possibly higher than would be expected. However, since our depreciation cost function uses the trade in values, the resulting depreciation cost reflects real world values.

Marginal vehicle operating cost is estimated in terms of distance traveled, and this assumption cancels out insurance cost in the marginal cost formula since these are usually defined in terms of vehicle age. Marginal vehicle operating cost (MC_{opr}) per mile is estimated as

$$MC_{opr} = 0.1227 + \left(\frac{0.104}{a}\right) \quad (6)$$

It is clear from equation (6) that marginal vehicle operating cost per distance decreases as the vehicle gets older. Intuitively, the longer the vehicle is utilized, the lower the marginal cost of running it becomes. This is mostly due to decreasing marginal deprecation cost over time (see table 4). In our analysis, we used an average vehicle age of 8.5 years, reflecting the national average in the United States, as reported in AAMA (1996).

User Interaction Costs: Congestion and Accident Costs

Congestion costs are defined as time loss and discomfort for drivers. The magnitude of these costs is directly related to the time lost and to user characteristics.

- Time loss is determined through the use of a travel time function and trip characteristics, such as distance between O-D pairs, traffic volume, and highway capacity. Once the trip characteristics are known, the travel time function is used to calculate the time lost in the traffic between each O-D pair.
- User characteristics, on the other hand, are expressed through the dollar value each user places on a specific unit of his or her time. However, user characteristics are not homogeneous and not easy to identify. Thus, in this study we use an average "Value of Time" (*VOT*). Small (1992) suggests that *VOT* should be taken as 50% of the gross wage rate. This value can vary among different states and cities. Thus, we decided to use a range of 40 to 170% of the pre-tax hourly wage rate as the *VOT* in our analyses. The New Jersey Department of Labor reports the hourly wage rate in 2000 as \$19 per hour (NJDOL 2000). Thus, our *VOT* ranges from \$7.6 to \$32.3.

In this study, we employed the commonly accepted travel time function, the Bureau of Public Road's (BPR) volume-capacity function. Using the

TABLE 4 Contribution Percentages of Operating Cost Categories

Year	Depreciation (percent)	Fuel, gas, oil, tires, parking, and tolls (percent)	Insurance (percent)
1	74	14	12
2	60	22	18
3	52	26	22
4	47	29	24
5	43	31	26
6	40	33	28
7	37	34	29
8	36	35	30
9	34	36	30
10	33	36	31
11	32	37	31
12	31	37	32
13	30	38	32

Note: An annual mileage of 13,000 miles is assumed.

BPR function, total congestion costs on link a to b, with a traffic volume of Q, is calculated as follows.

$$C_{cong} = QT_{ab}(VOT) = QT_0\left(1+0.15\left(\frac{Q}{C}\right)^4\right)(VOT) \quad (7)$$

The marginal congestion cost function is then the first order derivative in terms of traffic volume, Q.

$$MC_{cong} = \frac{\partial C_{cong}}{\partial Q} = Tab(VOT) + Q(VOT)\frac{\partial Tab}{\partial Q} \quad (8)$$

where

MC_{cong} is the marginal cost of congestion (dollars/hour)

VOT is the average value of time (dollars/hour)

T_0 is free-flow travel time between points a and b (hours)

T_{ab} is the travel time required to travel between points a and b (hours)

Q is the average volume on the link connecting points a and b (vehicles/hour)

C is highway capacity (vehicles/hour).

The first term in the right-hand side of equation (8) represents the time cost experienced by one user, and the second term stands for the cost imposed on the rest of the users on that link.

The second type of user interaction costs, accident costs, can be classified into two major groups:

- Foregone production or consumption by individuals or both, easily converted into monetary units
- Life-injury damages by users, not easily converted into monetary units.

The available New Jersey data contain a detailed accident summary for 1995, including the pedestrians affected, grouped by incident types and by county in New Jersey.

In order to estimate the cost of accidents over a given period of time, we need to know the accident occurrence rate (number of accidents over time) and the unit cost of an accident. If we develop a function to estimate the number of accidents occurring over a period of time, accident costs can also be measured by multiplying the number of accidents by their unit cost values. Clearly, costs vary, accident by accident. However, similar accidents have costs that fall more or less in the same range. Thus, we classified accidents as 1) fatal, 2) injury, or 3) property damage.[7]

There are also various geometric design features of a roadway that affect the possibility of an accident, such as the number of lanes, horizontal and vertical alignment, superelevation, sight obstructions, and so forth. However, it is not an easy task to include every variable in the accident occurrence rate function. Thus, the accident occurrence rate is assumed to be correlated only with highway functional type, average traffic volume, and the length of the highway. For this purpose, highways are grouped into three categories according to their functional properties. These are interstate, freeway-expressway, and arterial-collector-local.[8]

The generalized form of the total accident cost function is given as follows:

$$C_{acc} = \sum_{i=1}^{3} C_f p_{fi} + C_h p_{hi} + C_d p_{di} \quad (9)$$

[7] Vehicle fire and cargo spills are disregarded since their occurrence rates are relatively negligible.

[8] The classification of highways is based on the available accident data.

where

C_{acc} is the total accident cost per year (dollars/year)

C_f is the unit cost of a fatal accident per crash (dollars)

C_d is the unit cost of a property damage accident per crash (dollars)

C_h is the unit cost of an injury accident per crash (dollars)

p_{fi} is the number of fatal accidents per year for highway type i

p_{hi} is the number of personal injury accidents per year for highway type i

p_{di} is the number of property damage accidents per year for highway type i.

It should be noted that accident cost as given in equation (9) does not include the costs of congestion caused by accidents. In order to utilize the equation (9), we have to develop p_{fi}, p_{hi}, and p_{di} functions using the available accident data. As mentioned above, the number of accidents is assumed to be correlated with roadway length (M), as a measure of network properties, and average traffic volume (Q), as an output measure. The general form of the accident occurrence rate (the number of accidents over a given time period) function is given as follows:

$$p = \alpha_1 M^{\alpha_2} Q^{\alpha_3} \tag{10}$$

where $\alpha_1, \alpha_2, \alpha_3$ are the estimated coefficients of equation (10).

Nine regression analyses were run to estimate accident occurence rate as a function of average traffic volume and the roadway length for each highway category. Hence, we obtained 9 different functions. The results of the regression analyses are given in table 5. We have decided to exclude fatality accident occurrence rate functions for freeway-expressway and interstate highway functional types from our analyses since the coefficents in these functions are not statistically significant (see table 5). We suggest that when more data on accidents become available, these occurrence rate functions be reestimated.

TABLE 5 Accident Occurrence Rate Regression Analyses Results

	Property damage		Fatality		Injury	
Arterial-Local-Collector	Coefficient	*t*-value	Coefficient	*t*-value	Coefficient	*t*-value
Intercept	4.7E-7	–3.9189995	4.15E-5	–2.8057275	5.95E-9	6.1740294
Q	2.1937	5.1888142	0.7357	1.7986337	2.5084	7.1900767
M	0.4592	1.3204427	0.8945	2.6580631	0.7366	2.5664179
R^2	0.65		0.42		0.80	
Freeway and Expressway	Coefficient	*t*-value	Coefficient	*t*-value	Coefficient	*t*-value
Intercept	0.0139	–1.7571000	7.7523	0.7731267	0.1851	0.9552417
Q	0.9508	3.9950085	–0.1435	–0.5537863	0.6837	3.9563777
M	0.2317	1.2375911	0.6553	3.2139405	0.501	3.6822804
R^2	0.63			0.43		0.76
Interstate	Coefficient	*t*-value	Coefficient	*t*-value	Coefficient	*t*-value
Intercept	3.23E-5	–1.5835942	7.79E-5	–0.9158328	3.114E-10	0.9158328
Q	1.0924	1.8072909	0.8066	0.8808309	2.0963	0.8808309
M	0.9043	4.7104977	0.3316	0.6027988	0.9766	0.6027988
R^2	0.72			0.11		0.81

C_f, C_h, and C_d values cover both direct and indirect costs caused by an incident, and their values are taken from Miller and Moffet (1993). These values are given in table 6.[9]

The total accident cost function is developed for each highway type, based on the results obtained from the regression analysis and the unit cost values for each accident type, as shown in table 6. The marginal accident cost functions are determined simply by taking the first order derivative of the total accident cost function with respect to volume, Q.

arterial-local-collector

$$MC_{accc} = (0.007)M^{0.4592}Q^{1.1937} + (125.58)M^{0.8945}Q^{-0.2643} + (0.0022)M^{0.7366}Q^{1.5084} \quad (11)$$

freeway-expressway

$$MC_{acc} = (89.81)M^{0.2317}Q^{-0.05} + (18{,}257.87)M^{0.501}Q^{-0.3163} \quad (12)$$

interstate

$$MC_{acc} = (0.2394)M^{0.9043}Q^{0.0924} + \left(9.42 \cdot 10^{-5}\right)M^{0.9766}Q^{1.0963} \quad (13)$$

where
M is roadway length (miles) and
Q is average traffic volume (vehicles/day).

It is reasonable to think that high volumes of traffic reduce vehicle-flow speed and, thus, fatal accidents. However, Vickrey (1968) argues that the rate of total accidents increases with increasing average daily traffic. As seen in table 5, our estimated accident occurance rate functions support Vickrey's (1968) hypothesis.

Infrastructure Costs

Infrastructure costs include all long-term expenditures, such as facility construction, material, labor, administration, and right of way costs. Also included are interest over the lifetime of the facility, regular maintenance expenditures for keeping the facility in a state of good repair, and occasional capital expenditures for traffic-flow improvement.

TABLE 6 Accident Costs by Type

Accident type	Value per crash (dollars)
Fatality	4,113,956
Injury	144,291
Property damage	6,783

Note: The unit cost values are converted to year 2000 dollars, assuming an average 3.5% per year inflation rate.

Source: Miller and Moffet (1993)

Highway investment and its costs can be best described by defining input prices, output, and network properties (Levinson et al. 1996). Input includes the cost of all phases of construction, such as roadway design, land acquisition, labor, construction material, and equipment. Network properties represents the physical capabilities of the constructed highway facility, which includes the number of lanes, lane width, pavement durability, the number of intersections, ramps, overpasses, and so forth. In addition, environmental factors are important elements in highway construction. Highway location, demographics of the district, soil properties, geometry of land, weather conditions, and other factors have an effect.

In computing marginal infrastructure cost, new construction and land-acquisition costs cancel out since these costs are not a function of traffic volume, Q. Thus, maintenance and improvement are 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, labor, and so forth. Output implies the traffic volume on the roadway. The data employed include all types of maintenance and improvement works completed between 1991 and 1998 in New Jersey. Given the database, we decided to divide the maintenance and improvement works into three categories:

1. Major reconstruction with/without roadway widening

[9] Property damage cost is assumed to comprise only the damage to the vehicle. Any type of injury falls in the personal injury category.

2. Roadway widening with/without resurfacing
3. Resurfacing with/without minor roadway widening

The estimated cost function for each category follows.

$$C_{M1} = (7.877)tm^{0.445}tev^{0.373}Q^{0.256} \quad (14)$$
$$R^2 = 0.81$$

$$C_{M2} = (19{,}930.37)s^{0.364}ns^{0.116} \quad (15)$$
$$R^2 = 0.61$$

$$C_{M3} = tm^{0.7556} + Q^{1.2931} \quad (16)$$

where

s is total volume of surface course used, ft^3
tm is total material used, ft^3 (surface course, base course, and sub-base)
ns is number of overhead signs installed,
tev is total earthwork, ft^3 (excavated soil or removed material, embankment, and so forth)
Q is traffic volume (vehicles/day).

Functions (14), (15), and (16) provide close estimates of the cost of each type of roadway maintenance project. However, the functions are to be used on a "per project" basis. In other words, 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 valid methods of estimating resurfacing cycles (Small et al. 1989); however, we know of no practical methods for estimating the cycle of rest of the maintenance work categories. The first two maintenance work categories are required when the roadway is not capable of carrying the increased traffic. Its analysis requires a transportation demand model, which is out of the scope of this paper. Therefore, we have decided to exclude the first two cost categories from our marginal cost analysis.

Thus, the marginal cost function for resurfacing is calculated as follows:

$$MC_{inf} = 1.2931Q^{0.2931}\sum_{i=1}^{T}\frac{r}{1-e^{-rn_i}} \quad (17)$$

where

MC_{inf} is marginal maintenance cost in year 2000 (dollars/trip)
Q is traffic volume (vehicles/day)
T is number of resurfacing cycles throughout the lifetime of a pavement (25 years assumed)
n_i is time interval between each resurfacing dates and the year 2000 (years)
r is interest rate.

It should be noted that equation (17) considers all the resurfacing works done over the lifetime of the roadway. Ozbay et al. (2000) explains the method used to estimate the number of resurfacing cycles over the lifetime of a highway.

Environmental Costs

The environment costs caused by highway transportation regarded here include air pollution costs and noise costs. Development of specific cost functions for these environmental cost categories is beyond the scope of this study. Hence, we have adopted these cost functions from the germane literature.

Air Pollution Costs

Air pollution is defined as the change in ambient gas percentages and particulates resulting from human activities. Highway transportation accounts for a large portion of all air polluting activities through motor vehicle emissions. The contribution of highway transportation results either from the direct emission of these pollutants or from chemical reactions of these emitted pollutants with each other or with materials already existing in the atmosphere, such as PM_{10} (particulate matter 10 microns or smaller).

We consider the major pollutants emitted from motor vehicles to be volatile organic compounds (VOC), carbon monoxide (CO), and nitrogen oxides (NO_x). These pollutants have several adverse health effects on living organisms, land, crops, water, and air, among others. For a detailed description of these health effects, see Lynam and Pfeifer 1991.

In this study, we adopt an emission function to estimate the quantity of pollutant generated by motor vehicles. We put some factors aside, such as topographical and climatic conditions of the region, vehicle properties, vehicle speed, acceleration and deceleration, and fuel type. Next, unit cost values of each pollutant are calculated based on the methods presented in the literature. Unit cost calculations will be based on pollutant emission amounts in New Jersey, as reported by the Environmental Protection Agency (USEPA 1995).

Basically, we need to find the emission rate (grams/mile) for the pollutants VOC, CO, NO_x, and PM_{10}. Multiplying the emission rate with the total miles traveled in the considered network would give us the total amount emitted for each pollutant in New Jersey. The marginal cost function is developed simply by multiplying the unit cost values of each pollutant (dollars/gram) by the increase in the amount of pollutant emitted due to a unit increase in the traffic volume.

The proposed emission function is based on fuel consumption. It is assumed that the amount of pollutant released during motor vehicle operation is proportional with the amount of fuel consumed. The fuel-consumption function depends on the vehicle and is in quadratic form as follows (Ardekani et al. 1992).

$$F = 0.0723 - 0.00312V + 5.403 \cdot 10^{-5} V^2 \tag{18}$$

where

F is fuel consumption at cruising speed (gallons/mile) and

V is average speed (miles/hour).

The emission rates of each pollutant (grams/gallon) are 69.9 grams for CO, 13.6 grams per NO_x, and 16.2 grams for VOC (SYNCHRO). Since we do not have a direct PM_{10} emission function, we utilize an emission rate specific to New Jersey (0.0825 grams/mile). See Ozbay et al. 2000 for the specific reasons why the unit grams/mile is chosen.

The unit cost of each pollutant is given in table 7. The fuel-consumption function given in equation (18) is a function of speed, V, and thus a function of traffic volume, Q. Total air pollution cost for a link of one mile, with a traffic volume Q (vehicles/hour) is calculated as follows.

$$C_{air} = Q(0.01094 + 0.2155F) \tag{19}$$

$$MC_{air} = 0.01094 + 0.2155(F + Q\frac{\partial F}{\partial Q}) \tag{20}$$

where

C_{air} and MC_{air} are measured in dollars per mile per hour, and F is calculated by equation (18).

TABLE 7 Cost of Each Pollutant Type

	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**

VOC = volatile organic compounds
NO_x = nitrogen oxides
CO = carbon monoxide
PM_{10} = particulate matter 10 microns or smaller
N/A = not applicable

Sources: Morbidity costs are directly taken from Small and Kazimi (1995). However, mortality costs are calculated specifically for New Jersey by following the same method used in Small and Kazimi (1995). See Ozbay et al. (2000) section 3.4.1 for a detailed explanation.

Noise Costs[10]

There are several methods used to define noise in a numerical range so that any noise source can be examined as it is heard by the human ear. In general, it is accepted that a sound becomes annoying after 50 dB(A) (A-weighted decibles). Any sound level above this limit definitely imposes a cost on society.

Social costs of noise are generally estimated by calculating the depreciation in the value of residential units alongside highways. The closer a house is to a highway, the higher these costs are. In this study, we use the Noise Depreciation Sensitivity Index ($NDSI$) as given in Nelson (1982). $NDSI$ is defined as the ratio of the percentage reduction in the house value and the change in the noise level. Nelson (1982) suggests a value of 0.40% for the $NDSI$.

The house value depreciation function is defined as follows:

$$ND = N_h\left(L_{eq} - L_{max}\right)DW_{avg} \tag{21}$$

$$L_{eq} = 10\log Q - 10\log r + 20\log V + 20 \tag{22}$$

[10] "The same factors, which have brought us air pollution in crisis proportions, namely increasing population, urbanization, industrialization, technological change, and the usual relegation of environmental considerations to a position of secondary importance relative to economic ones, have also brought us the noise phenomenon" (Anthrop 1973).

where
ND is depreciation due to noise (dollars)
L_{eq} is defined as the Equivalent Sound Level (dB(A)). See Galloway et al. (1969)[11]
Q is traffic flow (vehicles/hour)
r is distance to the highway (feet)[12]
V is average speed of the traffic (miles per hour)
N_h is number of houses affected (number of houses per mile^2), calculated by multiplying the average residential density (RD, number of houses per mile^2) around a highway by the distance to that highway in feet (r) and the length of the relevant highway section in miles (d).[13]

$$N_h = 2(RD)rd \tag{23}$$

L_{max} is maximum acceptable noise level (50 dB(A) in this study)
D is percentage discount in value per an increase in the ambient noise level (0.4%)
W_{avg} is average house value (dollars), given in table 8.

Based on equations (21), (22), and (23), the noise cost function is developed as follows.

$$C_{noise} = 2\int_{r_1=50}^{r_2=r_{max}} \left(L_{eq} - 50\right) D W_{avg} \frac{RD}{5280} dr \tag{24}$$

where C_{noise} is the noise cost around a one-mile long roadway segment over so many years. Marginal cost is the first order derivative of equation (24) with respect to Q.

$$MC_{noise} = \frac{\partial C_{noise}}{\partial Q} = \frac{(RD)(r_2 - r_1)W_{avg}}{2{,}640}\left(\frac{10}{Q1n10} + \frac{20(\partial V \setminus \partial Q)}{V1n10}\right) \tag{25}$$

In this formulation, the total noise generated around a road segment is taken into account. Representing the maximum distance to highway, r_2 can be calculated by equating L_{eq} (equation (22)) to 50 dB(A), where the traffic noise is above dB(A).

TABLE 8 Housing Value in New Jersey

Value range	Dollars
Lower value quartile	158,410
Median value	228,940
Upper value quartile	317,385

RESULTS

For one-route marginal cost ($ORMC$) estimations, we selected one origin in each county in northern New Jersey. $ORMC$ values are calculated for the shortest routes between these selected origin-destination (O-D) pairs. In this process, we employed the marginal cost functions developed for each cost category presented. The generalized cost formula used in $ORMC$ calculations follows.[14]

$$ORMC_{r,s} = \sum_{i=1}^{k} FMC^i = \sum_{i=1}^{k} MC^i{}_{opr}d + MC^i{}_{cong} + MC^i{}_{acc} + MC^i{}_{inf} + MC^i{}_{air} + MC^i{}_{noise} \tag{26}$$

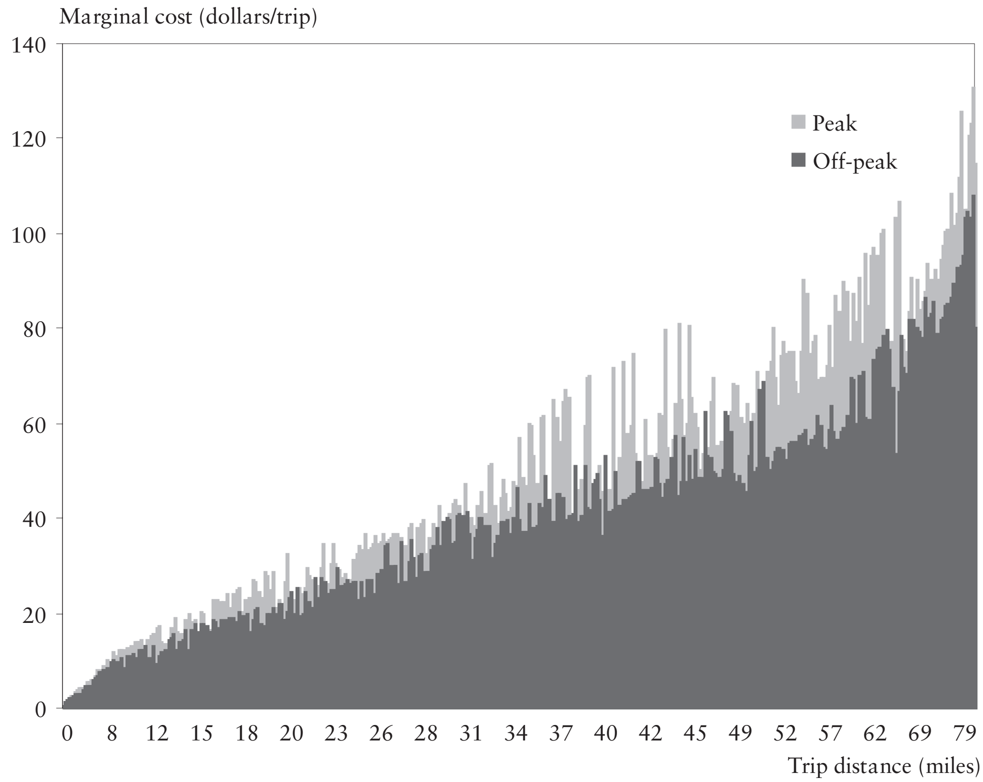
where
FMC is full marginal cost (dollars/mile)
MC_{opr} is marginal vehicle operating cost (dollars/trip)
MC_{cong} is marginal congestion cost (dollars/trip)
MC_{acc} is marginal accident cost (dollars/trip)
MC_{inf} is marginal infrastructure cost (dollars/trip)
MC_{air} is marginal air pollution cost (dollars/trip)
MC_{noise} is marginal noise cost (dollars/trip)
(r, s) is O-D pair
k is number of links between O-D pairs on the shortest route
d is trip distance (miles).

In total, we have 18,850 $ORMC$ values with their corresponding attributes. As mentioned, $ORMC$ values have a cost range based on the value of time (VOT) assumptions. We assumed a VOT range of 40 to 170% of the average hourly wage in New

[11] This function is only valid for the vehicle flows above 1,000 vehicles/hour.
[12] Minimum distance to a highway is assumed to be 50 feet.
[13] The multiplication by 2 in equation (23) is used to calculate the number of housing units on each side of the roadway.

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

FIGURE 4 *ORMC* Distribution with Respect to Trip Distance for Peak and Off-Peak Hours (*VOT* = $7.6)



Jersey. This enables us to better estimate full marginal cost under various time values. The analysis is also repeated for off-peak periods to observe the difference in the marginal cost values.

In figure 4, *ORMC* values are plotted with respect to trip distance for both peak and off-peak hours, assuming a *VOT* of $7.6/hour. 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 full marginal costs.

Figure 5 shows *ORMC* distribution with respect to trip distance when *VOT* is equal to $32.3, an assumed upper bound. It is clear that the difference in *ORMC* values for peak and off-peak hours are greater than those of figure 4. 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 overall costs. Thus, it is important to emphasize the effects of congestion-reduction measures in terms of overall costs.

Table 9 gives the *ORMC* functions with respect to trip distance (d) and time period for each *VOT* assumptions, estimated using the data points shown in figures 4 and 5. These functions can be used as a quick reference to the magnitude of *ORMC* values for given trip distances.

In order to observe the effect of highway functional type and the degree of urbanization 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 the degree of urbanization.

First, we analyze the effect of highway functional type on the *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, irrespective of trip distances. Thus, we examine this relationship for different trip distance ranges. For relatively short distances (that is, 0 to 10 miles) the routes with a higher percentage of local-collector highways tend to have smaller *ORMC* values.

Figures 6 and 7 depict the effect of the percentage of local-collector highways of the shortest routes on *ORMC* values during peak and off-peak hours for a trip distance of two miles. During peak and off-peak hours, as the local-collector highway

FIGURE 5 *ORMC* Distribution with Respect to Trip Distance for Peak and Off-Peak Hours (*VOT* = $32.3)

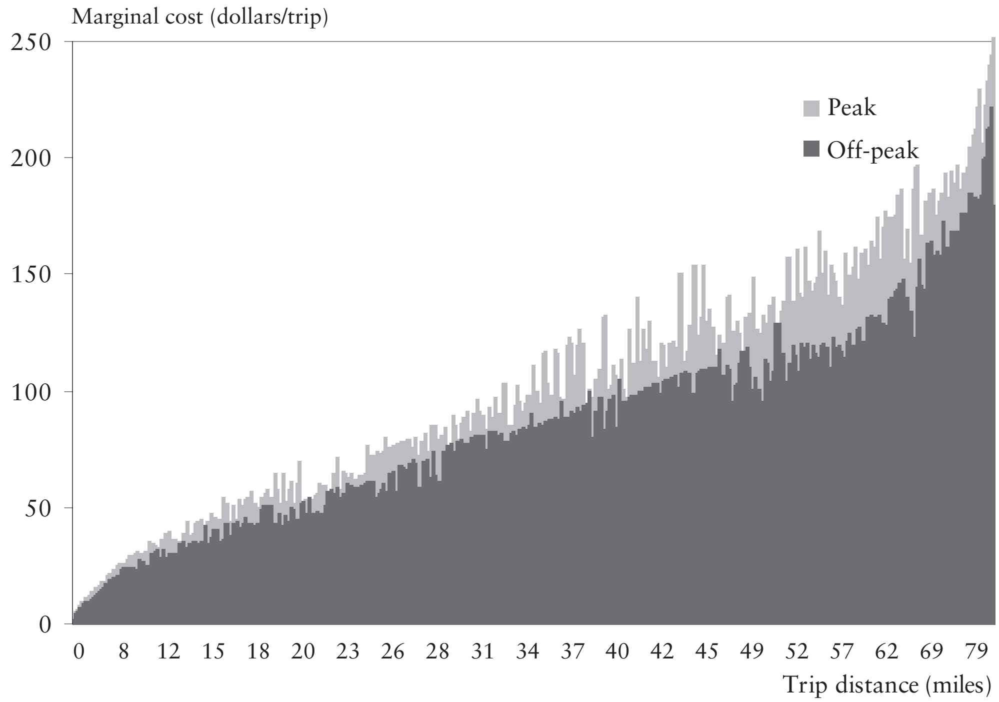


TABLE 9 Data Fitting for *ORMC* Values Given for Peak and Off-Peak Hours with Different VOT Values

	VOT = $7.6		*VOT* = $32.3	
	Equation	R^2	Equation	R^2
Peak	$y = 0.7568d$	0.857	$y = 1.846d$	0.923
Off-peak	$y = 0.6404d$	0.855	$y = 1.5421d$	0.907

Note: y is *ORMC* value (dollars/trip)
d is trip distance (miles)

type percentage increases, the *ORMC* value decreases. The same patterns obtained in figures 6 and 7 hold for trip distances up to 10 miles.

Figures 8 and 9 depict the variation of *ORMC* with respect to the percentage of minor arterial highway functional type for a trip distance of two miles. Unlike with local-collector highways, as the percentage of minor arterial highway of a route increases, the *ORMC* value increases as well. However, *ORMC* distribution with respect to the percentage of minor arterial road, as shown in figures 8 and 9, holds for trip distances up to three miles. For trip lengths between 3 and 10 miles, *ORMC* values tend to decrease as minor arterial percentage increases.

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 short-trip distances. As for principal arterials, sufficient information can be gathered for trip distances longer than three miles. Figure 10 shows that within the same trip distance range (3 to 10 miles), *ORMC* value increases with increasing principal arterial percentage for a given route.

ORMC distribution patterns change within the 0 to10 mile range because as trip distance increases, the percentages of each highway functional type changes as well. Up to three 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 three miles, the utilization of principal arterials becomes significant, and *ORMC* value increases due to the increased congestion along these routes. Finally, beyond 10 miles, minor arterial and local-collector type of highways are not utilized as significantly as are interstate-freeways-expressways and principal arterials.

FIGURE 6 *ORMC* **Distribution with Respect to Highway Functional Type Percentage During Peak Hours for Trip Distance of Two Miles (*VOT* = $7.6): Marginal Cost vs. Local-Collector Highway**

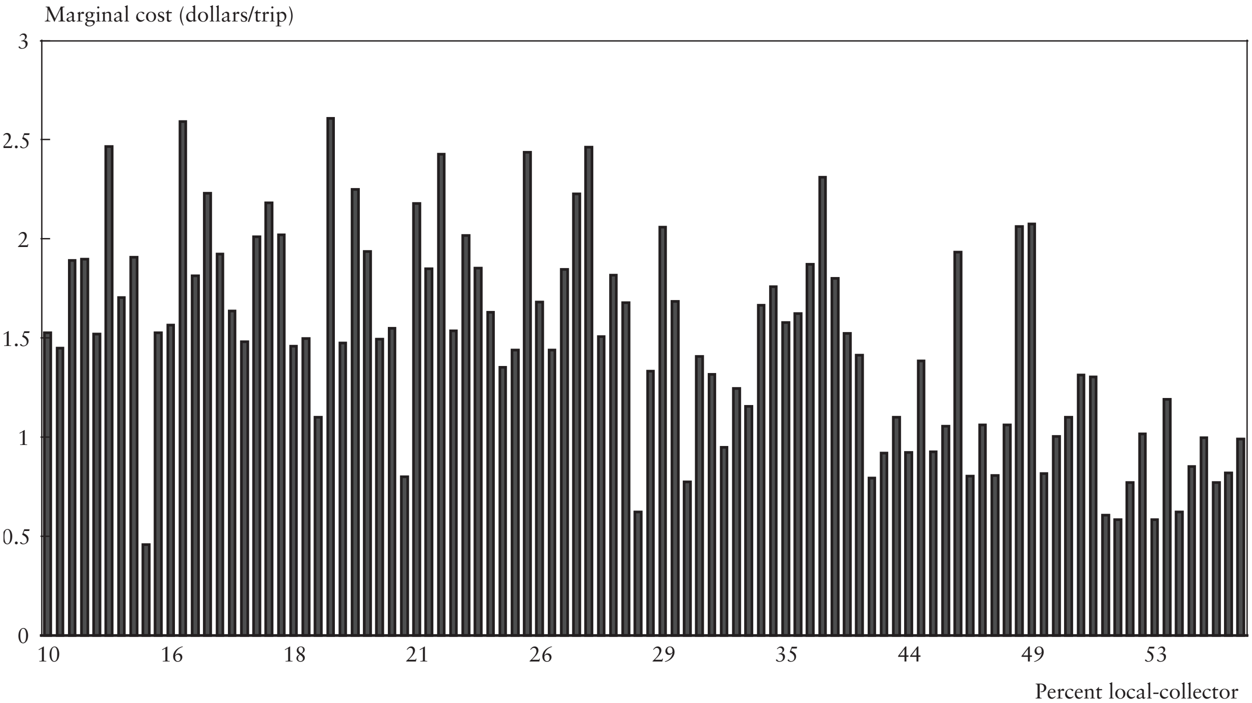


FIGURE 7 *ORMC* **Distribution with Respect to Highway Functional Type Percentage During Off-Peak Hours for a Trip Distance of Two Miles (*VOT* = $7.6): Marginal Cost vs. Local-Collector Highway**

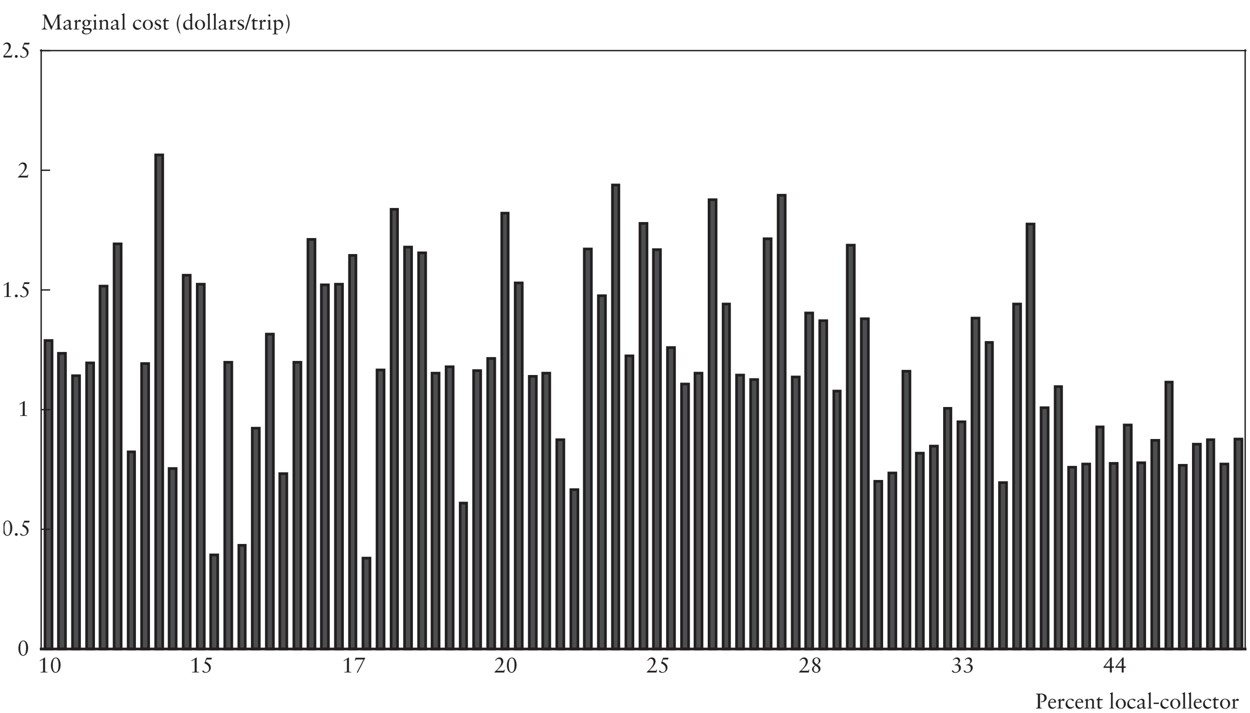


FIGURE 8 *ORMC* Distribution with Respect to Highway Functional Type Percentage During Peak Hours for a Trip Distance of Two Miles (*VOT* = $7.6): Marginal Cost vs. Minor Arterial Highway

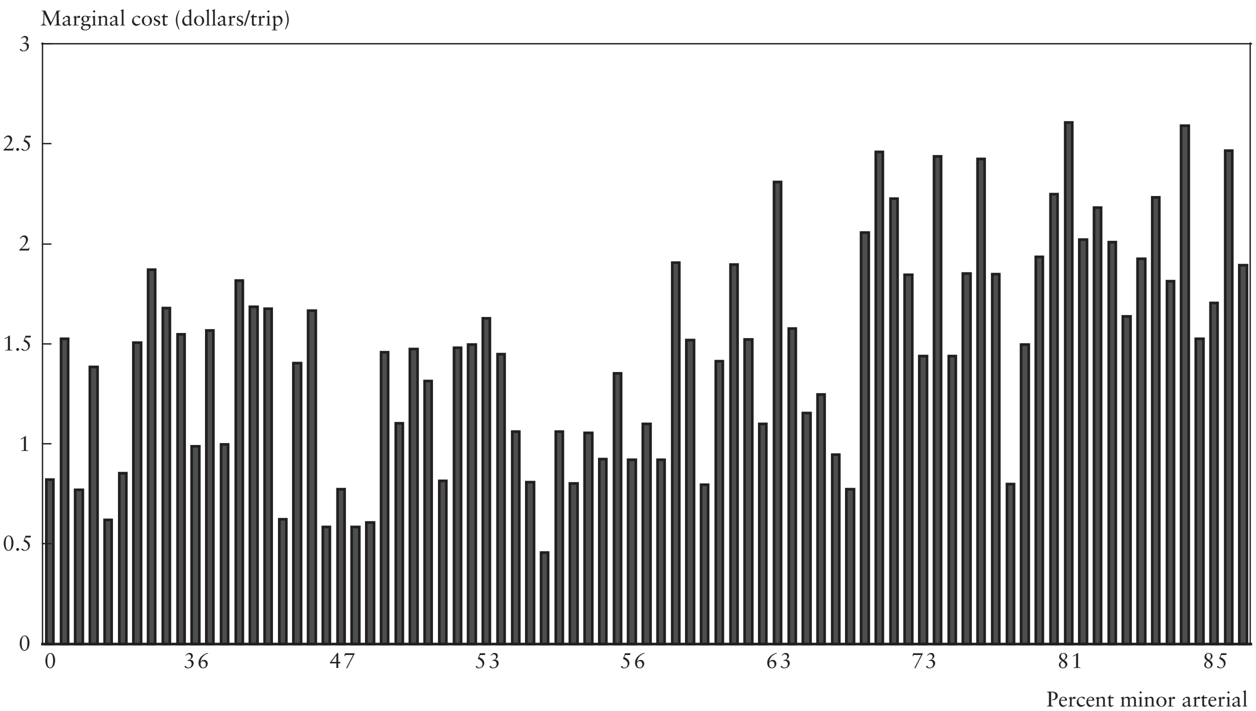


FIGURE 9 *ORMC* Distribution with Respect to Highway Functional Type Percentage During Off-Peak Hours for a Trip Distance of Two Miles (*VOT* = $7.6): Marginal Cost vs. Minor Arterial Highway

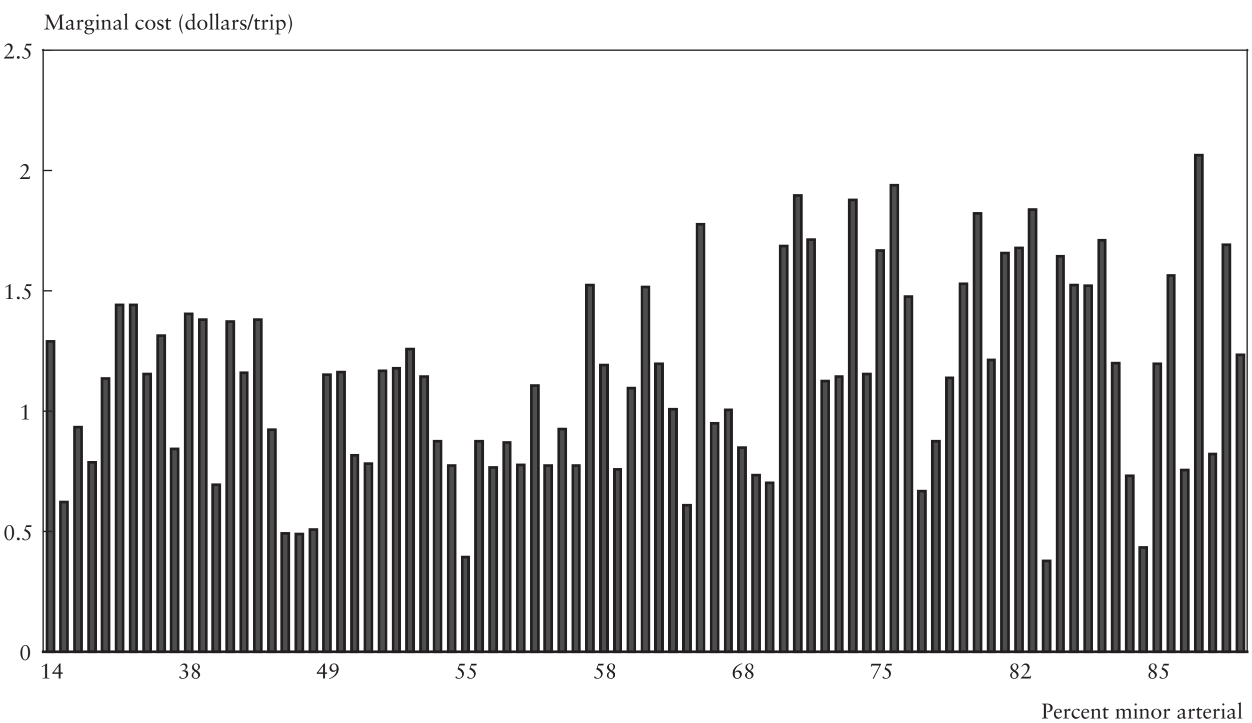


FIGURE 10 *ORMC* **Distribution with Respect to Highway Functional Type Percentage During Peak Hours for a Trip Distance of Seven Miles (*VOT* = $7.6): Marginal Cost vs. Principal Arterial**

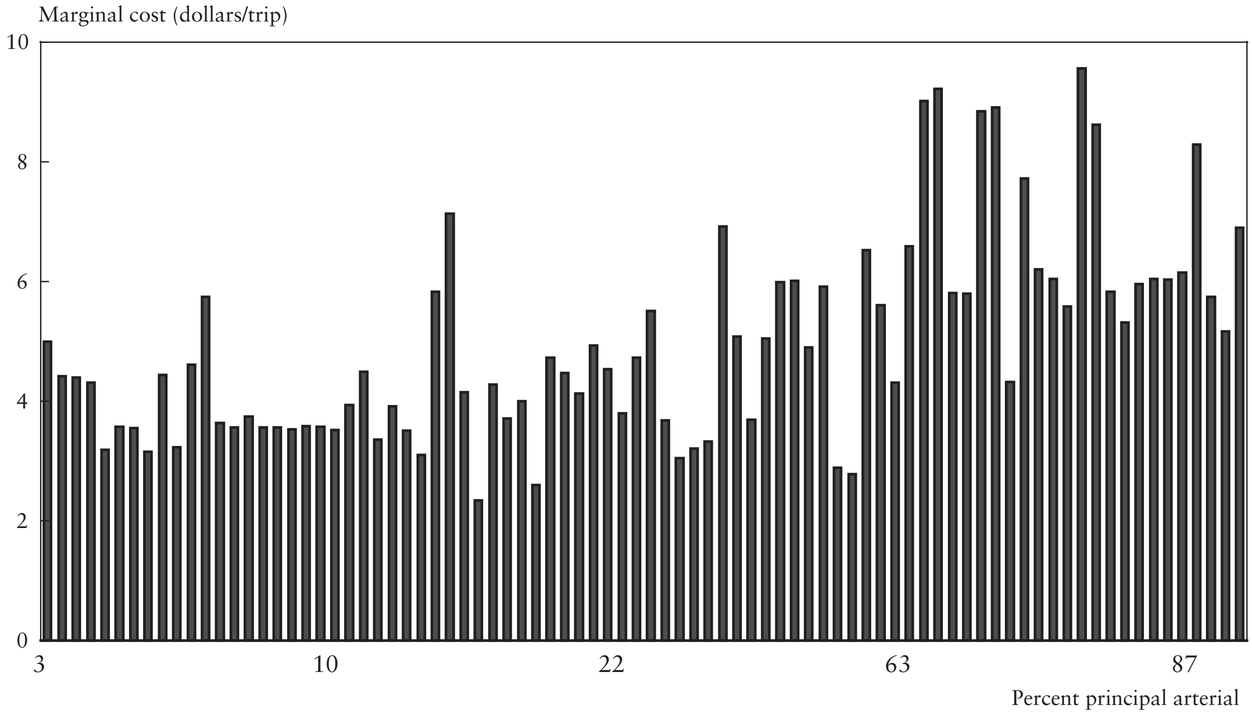


FIGURE 11 *ORMC* **Distribution with Respect to Highway Functional Type Percentage During Peak Hours for a Trip Distance of 25 Miles (*VOT* = $7.6): Marginal Cost vs. Interstate-Freeway-Expressway**

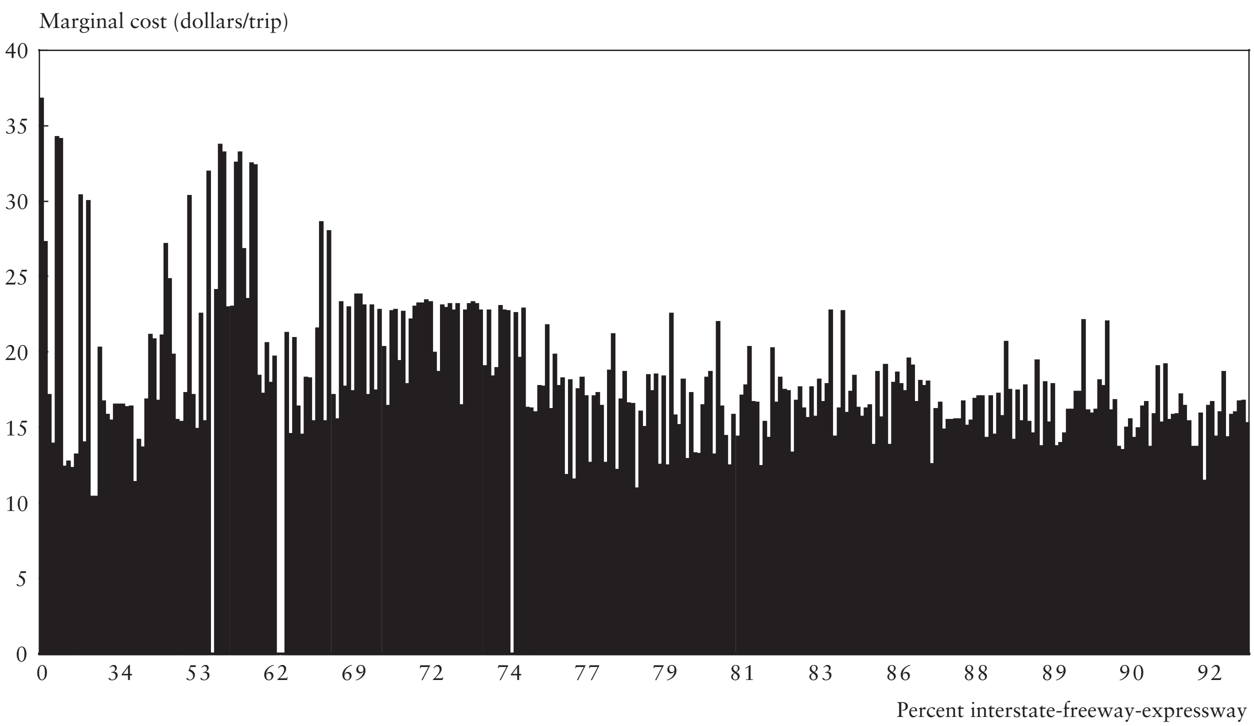
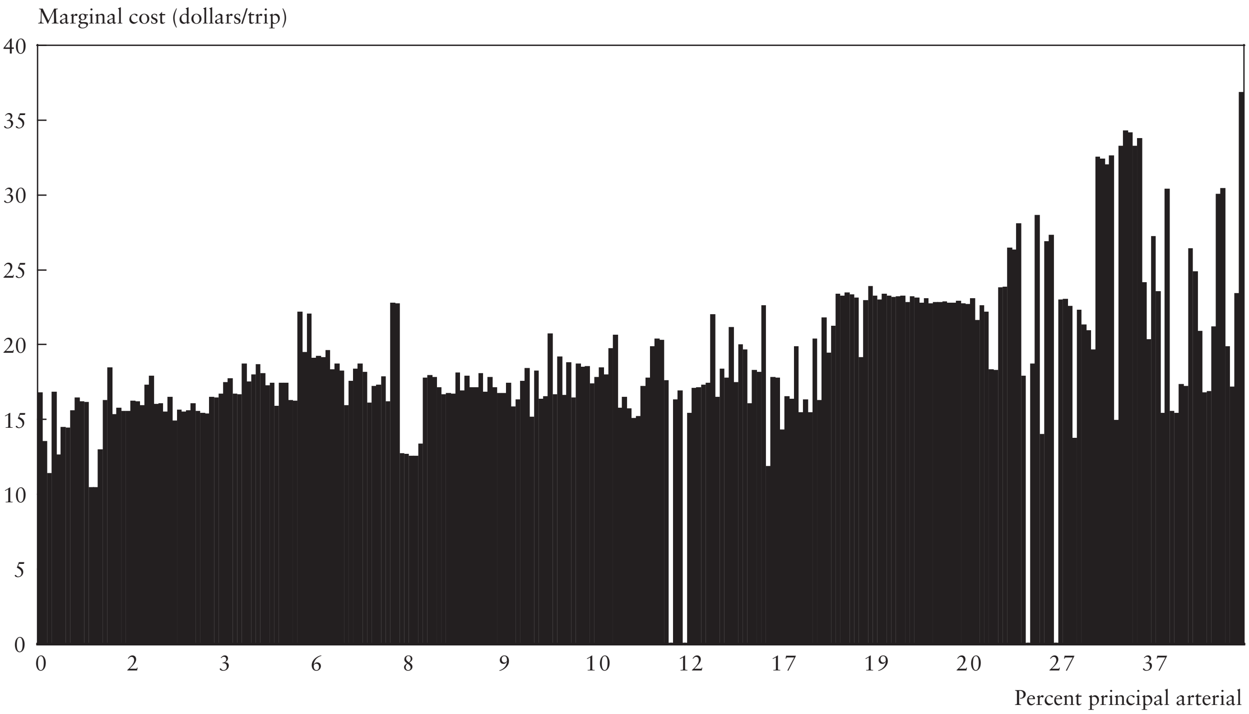


FIGURE 12 *ORMC* Distribution with Respect to Highway Functional Type Percentage During Peak Hours for a Trip Distance of 25 Miles (*VOT* = $7.6): Marginal Cost vs. Principal Arterial Highway



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 a trip distance of 25 miles. However, it should be noted that similar patterns are observed for all trip distances longer than 10 miles.

Figure 11 depicts the *ORMC* distribution with respect to interstate-freeway-expressway percentages for peak periods. *ORMC* values tend to decrease as interstate-freeway-expressway percentage increases. The same pattern holds during off-peak periods as well. Figure 12 depicts *ORMC* distribution with respect to percentage of the principal arterial type. It is seen that the pattern in figure 10 is valid for the 25-mile trip range. As the trip distance exceeds approximately 50 miles, the interstate-freeway-expressway functional type comprises most of the route distance. This fact restricts the analyses of *ORMC* distribution with respect to principal arterial as well as to the percentage of interstate-freeway-expressway.

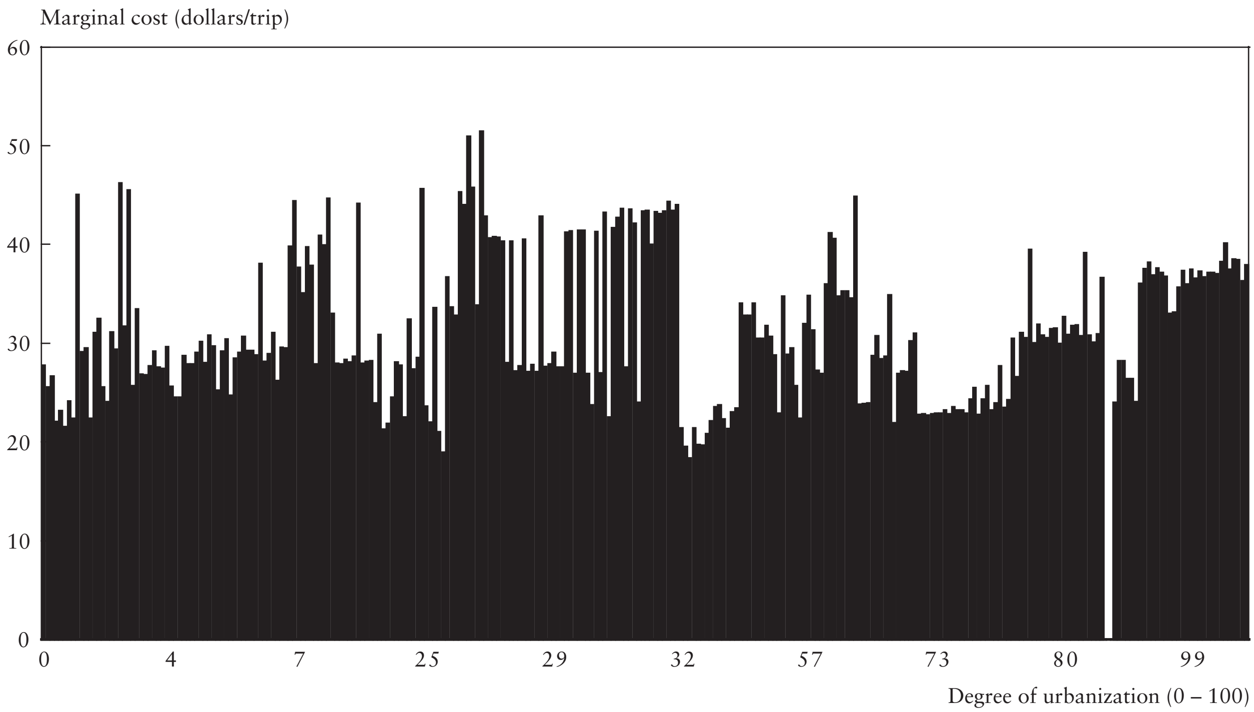
Finally, we attempt to correlate the variation in *ORMC* values and degree of urbanization using the data generated. Figure 13 shows the *ORMC* variation with respect to percentage of urbanization over a given trip distance. Similar analyses are done for all the trip distance ranges both for peak and off-peak periods. However, *ORMC* variations with respect to degree of urbanization do not follow a typical pattern. Thus, we can conclude that the degree of urbanization around highways does not necessarily imply an increased congestion level.

EVALUATION OF THE CURRENT PRICING POLICY

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

As stated in section 2, highway marginal cost pricing requires that every user be held responsible for the cost he or she imposes on the rest of the traffic with his or 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 external-

FIGURE 13 *ORMC* Distribution with Respect to Degree of Urbanization During Peak Hours for a Trip Distance of 40 Miles (*VOT* = $7.6): Marginal Cost vs. Degree of Urbanization



ities through the *FMC* methodology, we can measure the effectiveness of highway pricing policies in New Jersey.

Although average congestion cost and vehicle operating costs are fully experienced by the users, infrastructure and maintenance costs 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 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 that portion is directly imposed on the rest of the traffic by an additional trip. In our analysis, we have calculated congestion externalities. As for accident externalities, we have adopted a ratio of marginal to average accident cost of 1.52 in our analyses (Newberry 1988). Finally, we consider air pollution and noise costs as external costs to the rest of the traffic and society.

However, the detailed analysis of this task is not straightforward because trips have several quantitative and qualitative measures that cannot be grouped together easily. Consider, for example, the difference between a 50-mile trip and a 3-mile trip, or 2 trips with the same distance but on different highway types. Due to these differences, 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 ranging from 10 to 15 miles[15] and then weighted the averages for peak and off-peak hours. The average *FMC* values by each cost category are presented in table 10. It should be noted that the contributions of each cost category to *FMC* as shown in table 10 are not unique for all trip distance ranges; however, we believe that table 10 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, we calculate the external cost of making a trip within a distance range of 10 to 15 miles as $1.252.

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

[15] The "Summary of Travel Trends" (USDOT FHWA 1997) reports an annual national average vehicle trip length of 9.06 miles. A value specific to New Jersey is not available. Thus, we have chosen a range of 9 to 15 mile trip length.

TABLE 10 Full Marginal Cost by Categories for a Trip Distance Range of 9 to 15 Miles

Operating cost (dollars)	Congestion cost (dollars)	Congestion externality	Accident* cost (dollars)	Infrastructure cost (dollars)	Air pollution cost (dollars)	Noise cost (dollars)
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

for New Jersey was collected through federal and state fuel and vehicle tax, state and local tolls in 1998 as highway user revenues (USDOT FHWA 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 2000).[16] This is the average amount that the government charges each user per trip. Comparing this amount with our FMC, we observe that it is less than what we regard as necessary to compensate for the full marginal cost per trip.

What, then, should be the correct amount of increase in user fees imposed on users to compensate for the marginal roadway pricing in New Jersey? 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 in user fees only through a state fuel tax. The annual user revenue that should be collected becomes \$1.252 × 6.4386 billion trips (see footnote 16), equal to \$8,061,127,200. Assuming the federal vehicle and fuel tax revenues (\$962,433,000) and state and local tolls revenues (\$619,862,000) remain the same, the dollar amount the state needs to collect is now \$8,061,127,200 – (\$962,433,000 + \$619,862,000), or \$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 minus \$631,506,000 equal to \$5,847,326,200 would be the total amount that the state government needs to collect by state fuel tax only (USDOT FHWA 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 \$1.247 per gallon (USDOT FHWA 1999). This additional amount is far more than the current state fuel tax of \$0.1038 per gallon.[17]

TABLE 11 Fuel Prices and Percent Taxes in European Countries

Country	Percent taxes[a]	Tax	Price per gallon[b]
United Kingdom	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 (Recommended)	47.3	1.563[c]	\$3.303

[a]Gas tax as a percentage of retail price of gallon of gas
[b]Retail price per gallon of premium leaded as of September 2000
[c]Tax amount includes federal tax plus our recommended state fuel tax, \$1.247, instead of the current state fuel tax of \$0.1038 per gallon

Source: International Energy Source, National Energy Information Center, Quoted in *The Detroit News* 9/20/2000.

Kulash (2001) states, "There are valid social and economic reasons why road users should pay for the full range of costs that they impose on the public, but they pose a social and economic shock as well." Thus, although the collection of this revenue through the gas tax is not an impossible task, given the fact that compared to European countries this amount in the United States is considerably less, it does not appear to be an easy policy to sell to the American people, given the historical realities of this country. Table 11 presents the fuel tax charged in different countries in Europe as a percentage of the fuel price. As seen, the current fuel tax in the

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

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

United States is far less than in European countries. Even our estimated fuel tax percentage is less than the values in effect in European countries.

As we mentioned, the objective of marginal roadway pricing is to reduce congestion by charging users the additional amount that they impose on others. The concept has valid economical reasons on how to achieve optimal pricing. However, from our results it is clear that the concept presents serious practical difficulties regarding its political consequences. Though our calculation methodology is straightforward and based on averages, it demonstrates the extent of the difficulty of this problem. Here, our first scenario was to increase only the fuel tax. There are other means to collect the same of amount of revenue to compensate for the full marginal cost per trip, such as tolls. The introduction of advanced technology such as automatic vehicle identification systems can serve well for this specific purpose of imposing trip-based charges. On the other hand, it is clear that increased gas taxes and tolls will reduce the demand for highways, which will reduce the external costs such as congestion, pollution, and others. This will reduce the *FMC* per trip and the amount of taxes and tolls needed to a more acceptable level. However, this kind of dynamic analysis of the change of demand as a result of pricing is beyond the scope of this paper.

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 New Jersey. The variation in marginal cost value due to trip distance, degree of urbanization, and highway functional type are analyzed. Each set of observations is made for different VOT assumptions and time periods (peak and off-peak hours). Our main conclusions follow.

1. The difference in the marginal cost value for peak and off-peak hours becomes more significant with longer trip distances due to the increase in congestion costs.
2. It is estimated that marginal costs decline as a percentage of trip distance performed on freeway and expressway-type facilities increased.
3. It is observed that along the routes that have a higher percentage of principal arterials, marginal costs tend to increase.
4. Urbanization around the highways has no significant effect on 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 the amount required to meet the marginal roadway-pricing criterion.

These results can be used by policymakers to assess the effectiveness of the overall transportation system. For example, the finding that longer trips have considerably higher costs, mainly due to congestion, can be used to develop proper congestion toll schemes. In general, the evaluation of a decision of whether or not to invest in a new facility can be facilitated by comparing marginal social benefits with the germane marginal social costs, given a specific location.

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

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