Freeway Congestion Pricing: Another Look

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The rationale underlying congestion pricing is set forth. The level of congestion charges is based upon the freeway speed-flow curves contained in the 1985 *Highway Capacity Manual* and its 1994 update. Dollar values for the time costs incurred are developed on the basis of an annual household income of $33,000 and actual motorist studies using a time value of 15 cents per minute. The calculation results in congestion costs of about $0.35 to $0.87 per vehicle-kilometer ($0.61 to $1.40 per vehicle-mile) on the basis of the 1985 HCM speed-flow curves and about $0.04 to $0.06 per vehicle-kilometer ($0.06 to $0.09 per vehicle-mile) on the basis of the 1993 updated curves. Finally, some of the practical concerns associated with implementing freeway congestion pricing programs are discussed.

Growing congestion on urban transportation facilities has focused national efforts on congestion management—the management of both supply and demand to minimize congestion. Congestion pricing has received renewed attention as one means of rationalizing the use of congested roads by requiring motorists to pay for the costs they impose on others.

The concept of congestion pricing has been proposed by economists for more than three decades. Early studies by Vickery and Walters, among others, provided a conceptual and theoretical framework and attempted to quantify the levels of congestion charges through econometric analysis (*1–3*). More recent discussions, such as those set forth in *TR News* (*4*), describe the role, rationale, and limitations of congestion pricing.

The analysis and discussion that follows deals with one key aspect of congestion pricing: quantifying the actual congestion charges associated with freeway travel. The paper (*a*) presents the overall rationale underlying congestion pricing, (*b*) defines the basic concept of marginal (social) cost pricing, (*c*) quantifies the marginal costs on the basis of established speed-flow curves for freeways, and (*d*) sets forth emergent implications.

BACKGROUND AND RATIONALE

Congestion pricing has been used in several sectors of the economy for many years. Electric utility companies have set lower prices for off-peak use. Telephone calls are less expensive at night than during the day. Restaurants provide less expensive "early bird" specials.

There are also a limited number of examples in the transportation sector. The Washington Metro system has lower fares in off-peak periods. The Metro-North Commuter Rail system has lower off-peak round-trip fares (although the monthly commutation fares actually discount peak trips). Singapore has an automobile licensing scheme around its central area that involves charges for certain groups of road users during peak travel periods; its long-range plans call for an islandwide electronic road-pricing system.

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Several public policy and economic reasons underly congestion pricing:

- Higher charges during peak travel periods can manage demand by reducing or spreading peaks or by shifting some travelers to other routes or modes.
- Peak travel demands require additional investments in transport capacity.
- Peak-hour travelers (especially automobile drivers) add to congestion and thereby impose congestion costs on the general traffic stream.
- Revenues obtained can be used to improve the transportation system.

MARGINAL COST PRICING

A key concern in congestion pricing is determining the appropriate level of congestion charges. People in vehicles on congested roads both incur and impose delays. Charging people for both of these counts would amount to double charging. Economic theory, therefore, calls for setting the congestion prices at levels that reflect the social marginal costs, that is, the marginal social costs imposed on others.

The various marginal costs concepts are shown in Figure 1 for a 1-km (0.62-mi) section of road. Volumes are shown on the X axis and costs (i.e., travel times) on the Y axis. At low volumes, up to V_0, there is no increase in travel costs (times) as volumes increase. Beyond this point, average costs increase with increasing volumes. Thus, for volumes 1 and 2, respectively, the average cost increases from C_0 to C_1 and C_2.

The marginal cost curve is designated by $M(V)$. This curve is always above the average cost curve when the average cost curve is increasing. This curve represents the increased cost per traveler resulting from an increase in the number of vehicles using the road, $\Delta C/\Delta V$. Thus, the addition of a Vth user imposes costs on all users, because all users travel at the reduced speed. The $M(V)$ curve exceeds the $C(V)$ curve by the amount of the increased costs imposed on other travelers by the Vth entrant. These differences are denoted by a_1, and a_2. The total marginal costs, MC (i.e., $a_1 + b_1$ or $a_2 + b_2$) are as follows:

$$MC = \frac{\Delta C_1}{\Delta V_1} = \frac{V_1C_1 - V_0C_0}{V_1 - V_0} \quad (1)$$

$$MC = \frac{\Delta C_2}{\Delta V_2} = \frac{V_2C_2 - V_1C_1}{V_2 - V_1} \quad (2)$$

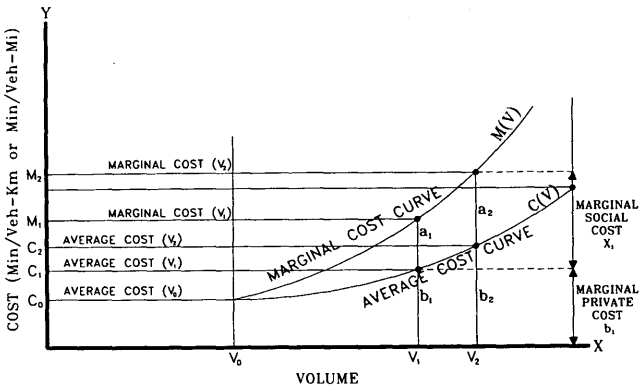

FIGURE 1 Average and marginal cost curves.

or, more generally,

$$MC = \frac{\Delta C_i}{\Delta V_i} = \frac{V_i C_i - V_{i-1}\, C_{i-1}}{V_i - V_{i-1}} \tag{3}$$

where

V_{i-1} = initial volume,
V_i = final volume,
C_{i-1} = costs (or time) at V_{i-1}, and
C_i = costs (or time) at V_i.

The social or external marginal costs represent the costs imposed on other vehicles by the additional traffic. These costs are noted as X on Figure 1. They can be defined as follows:

$$MSC \;=\; X \;= \frac{\Delta t V_2}{\Delta V} = \frac{t_2 - t_1}{V_2 - V_1} \tag{4}$$

A simple numerical example illustrates its application: If the initial volume is 1,500 vph and the final volume is 2,000 vpm, then the change in volume is = 500 vph; and if the initial travel time is 0.74 min/km (1.2 min/mi) and the final travel time is 1.24 min/km (2.0 min/mi), then the change in travel time is 0.50 min/km (0.8 min/mi). Then

$$X \;=\; \frac{(0.5)\,(2000)}{500} \;=\; 2.0 \text{ min/km } (3.2 \text{ min/mi})$$

QUANTIFYING MARGINAL COSTS

Marginal costs associated with freeway traffic congestion depend on how travel speeds decline as traffic flows increase. Such speed-flow relationships vary by facility and location. Generalized relationships, assuming ideal conditions, are set forth in the 1985 *Highway Capacity Manual* (HCM) (*5*, Table 3-1) and in an update (*6*, Table 3-1).

Accordingly, the marginal social costs associated with freeway travel were quantified on the basis of established speed-flow relationships, assuming a 1-km road section. The costs based on the 1985 HCM speed-flow data are shown in Table 1 (*5*). The costs based on the approved revisions to the HCM are shown in Table 2 (*6*).

TABLE 1 Marginal Social Costs for Basic Freeway Sections, 1985 HCM (*5*)

LOS	Vehicles per Lane per Hour (V)	ΔV	Minutes per Vehicle Kilometer (t)	Δt	Marginal Social Cost $\frac{V_2\, \Delta t}{\Delta V}$
112.6-KPH (70-MPH) Design Speed					
A	700		.62		
		400		.03	.08
B	1100		.65		
		450		.04	.14
C	1550		.69		
		300		.12	.74
D	1850		.81		
		150		.43	5.73
E	2000		1.24		
96.6-KPH (60-MPH) Design Speed					
B	1000		0.75		
		400		0.05	0.17
C	1400		0.80		
		300		0.09	0.53
D	1700		0.89		
		300		0.35	2.33
E	2000		1.24		
80.5-KPH (50-MPH) Design Speed					
C	1300		0.87		
		300		0.06	
D	1600		0.93		0.32
		300		0.40	
E	1900		1.33		2.53

The following should be kept in mind:

- Data are given for 112.6-, 96.5-, and 88.5/80.5-kph design or operating speeds. These correspond to 70-, 60-, and 55/50- mph design or operating speeds, respectively.
- A 1-km section of road is assumed.
- Costs are given in terms of travel time for a 1-km section of road.
- Entries are presented for each break in the levels of service.

The marginal social costs, expressed in minutes per vehicle-kilometer, increase as the number of vehicles per lane per hour increases. The increases reflect the shape of the speed-flow curves (expressed in minutes per kilometer). The highest marginal social costs generally are experienced as freeway volumes approach or exceed 2,000 vehicles per lane per hour as usually happens when the level of service (LOS) changes from D to E. This is the point at which congestion normally occurs, as defined by both traffic engineers and driver perceptions.

The boundary between LOS D and LOS E describes operation at capacity. Any disruption to the traffic stream, such as vehicles entering from a ramp or changing lanes, can cause other vehicles to give way to admit the vehicle. This can establish a disruption that propagates throughout the upstream traffic flow. The traffic stream has no ability to dissipate; even the most minor disruption or incident can be expected to produce a serious breakdown in

TABLE 2 Marginal Social Costs for Basic Freeway Sections, 1994 HCM Update (6)

LOS	Vehicles per Lane per Hour (V)	ΔV	Minutes per Vehicle Kilometer (t)	Δt	Marginal Social Cost $V\,\Delta t / \Delta V$
112.6-KPH (70-MPH) Free Flow Speed					
A	700		0.53		
		420		0.00	0.00
B	1120		0.53		
		524		0.02	0.06
C	1644		0.55		
		371		0.04	0.22
D	2015		0.59		
		185		0.03	0.36
E	2200		0.62		
96.6-KPH (60-MPH) Free Flow Speed					
A	600		0.62		
		360		0.00	0.00
B	960		0.62		
		480		0.00	0.00
C	1440		0.62		
		384		0.03	0.14
D	1824		0.65		
		476		0.05	0.23
E	2200		0.70		
88.5-KPH (55-MPH) Free Flow Speed					
A	550		0.68		
		330		0.00	0.00
B	880		0.68		
		440		0.00	0.00
C	1320		0.68		
		440		0.00	0.00
D	1760		0.68		
		440		0.07	0.35
E	2200		0.75		

traffic flow and extensive queuing. Maneuverability becomes extremely limited, and the level of physical and psychological comfort afforded the driver is extremely poor (5).

Accordingly, the marginal social costs associated with operation at LOS E were assumed to best reflect congestion costs. These costs are summarized in Table 3 for various free-flowing speeds and speed-flow relationships. They define the limits for setting congestion prices. In summary:

- Congestion costs, based on the 1985 speed-flow curves, range from 2.33 to 5.73 min per vehicle-kilometer (3.80 to 9.33 min per vehicle mile). [The 5.73 min per kilometer figure is based on a sharp decline in the speed-flow curve as occurs when volumes increase from 1,850 to 2,000 vph for 112.6-kph (70-mph) free-flow speeds.]
- The updated speed-flow curves are much flatter than those for 1985. The flattening reflects factors such as greater driver familiarity with freeway driving and improved freeway designs. Consequently, the resulting congestion costs are considerably less, approximating 0.4 min per vehicle-kilometer (0.6 min per vehicle mile).

TABLE 3 Comparative Marginal Social Costs for Freeways

Free-Flowing Speed	Maximum Flow Conditions, Speed-Flow Curve 1985	1993
112.6 KPH (70 MPH)	5.73	0.36
96.6 KPH (60 MPH)	2.33	0.23
80.5–88.5 KPH (50–55 MPH)	2.53	0.35

Note: Measurements given in minutes per vehicle kilometer.

The dollar costs of freeway congestion were estimated by assigning dollar values to the time costs incurred. The actual value of time depends upon the location involved and the proportion of commuter trips made for work purposes. Thus, there is wide variation in congestion costs from area to area.

The values of time were estimated by two basic methods: (a) allocating varying proportions of the national average household income to peak-hour travelers and (b) applying values of time actually used in toll road financial feasibility studies.

Median household income in 1990 reportedly was approximately $30,000. Assuming a 10 percent growth to 1993, results in an annual median household income of $33,000, about $.26 per minute. This value then was discounted to reflect nonwork travelers in the peak hour traffic (i.e., 25 to 50 percent).

Table 4 presents the 1993 values of time used in recent toll road studies. The final weighted value of time ranges from about $0.14 to $0.20 per minute.

The resulting dollar costs of congestion are set forth in Table 5. A time cost of about $0.15 per minute, a value commonly used in toll road studies, results in congestion costs of about $0.38 to $0.86 per vehicle-kilometer ($0.57 to $1.40 per vehicle-mile) on the basis of the 1985 speed-flow curves. The 1994 speed-flow curves yield costs of about $0.03 to $0.05 per vehicle-kilometer ($0.06 to $0.09 cents per vehicle-mile).

IMPLICATIONS

Congestion prices derived reflect assumed values of time, and, above all, the shape of the speed-flow curves. Moreover, the speed-flow curves represent idealized conditions that rarely exist on most urban and suburban freeways, especially those with design and operating problems.

Lane drops, grades, points of route convergence, and areas of heavy merging or weaving will tend to result in congested operations at volumes considerably less than those identified in the idealized relationships. For these reasons, many older freeways such as the Long Island Expressway and I-95 in Southwestern Connecticut have peak-hour speeds of less than 55 kph (about 35 mph). In such cases, congestion costs average 2.2 to 2.5 min per kilometer (3.5 to 4.0 min per mile), or about $0.37 per vehicle-kilometer ($0.60 per vehicle-mile).

Thus, in reality, the speed-flow curves will vary from freeway to freeway and along different sections of the same freeway, resulting in a range of facility-specific congestion prices. Therefore, the actual operating conditions of any freeway should be taken into account in establishing appropriate congestion prices.

TABLE 4 Value of Time Comparisons

Project/Location:	Sumner/Callahan Tunnel Boston, Massachusetts	S.R. 91 Riverside-Orange County California	Creek Turnpike Extension- Tulsa, Oklahoma	Conway Bypass, Horry County, South Carolina
Year of Study:	1992	1992-93	1993	1993
Median Household Income in Primary Area of Demand: (estimated in current 1993 dollars)	$34,662	$64,800	$27,558	$30,560
Unweighted Value of Time: (cents per minute)	25.1	(B)	23.8	25.0
Final Weighted Value of Time: (cents per minute) (A)	19.8	Peak: Single Occupant Vehicle - 20.0 Multiple Occupant Vehicle - 28.8	14.0	Seasonally Calculated: Winter - 15.0 Summer - 19.0
Assumptions Related To Final Weighted Value:	1. Average annual household worker hours assumed at 2,300 hours/year 2. Trip Purpose Distribution: a - To/from work = .750 b - During work = .150 c - Soc./Rec./Other = .100	1. Average Annual Household worker hours census derived 2,300 hours/year 2. Peak Hour Trip Purpose Distribution: a - To/from work = .700 b - Other work = .100 c - Non work = .200	1. Average Annual Household worker hours assumed at 2,080 hours/year (ASHTO Standard) 2. Trip Purpose Distribution: a - To/from work = .321 b - During work = .182 c - Soc./Rec./Other = .497	1. Average household worker assumed at 2,080 hours/year (ASHTO Standard) 2. Trip Purpose Distribution: Summer a - To/from work = .182 b - During work - Negligible c - Soc./Rec./Other = .818 Winter a - To/from work = .340 b - During Work = .164 c - Soc./Rec./Other = .496

SOURCE: Jeff Byer, Wilbur Smith Associates, New Haven, Connecticut

NOTES: (A) Final weighted value of time reflects trip purpose distribution and path choice factors. Path choice factors range from 0.4 to 0.8 for work, 1.0 during work and 0.4 for other purposes.

(B) Median Household Income not used. Method of calculation based on Stated Preference Survey Methodology.

TABLE 5 Estimated Marginal Social Costs of Freeway Congestion (Dollars per Vehicle Kilometer)

	$33,000 Annual Household Income				
	Percent of Hourly Wage Rate Applied			Toll Road Studies	
	50	75	100		
Dollars/Hour	7.94	11.90	15.87	9.00	10.20
Cents/Minute	13.22	19.84	26.45	15.00	17.00
Design/Operating Speed	Actual Costs				
1985 HCM					
112.6 KPH (70 MPH)	0.76	1.14	1.52	0.86	0.97
96.6 KPH (60 MPH)	0.31	0.46	0.62	0.35	0.40
80.5 KPH (50 MPH)	0.33	0.50	0.67	0.38	0.43
1994 HCM					
112.6 KPH (70 MPH)	0.05	0.07	0.10	0.05	0.06
96.6 KPH (60 MPH)	0.03	0.05	0.06	0.03	0.04
88.5 KPH (55 MPH)	0.05	0.07	0.09	0.05	0.06

Peak-hour speeds can be used as a basis for determining appropriate congestion prices:

- If peak-hour speeds exceed 70 to 80 kph (about 45 to 50 mph), the 1993 speed-flow curves can be used, resulting in a congestion cost of about $0.06 per vehicle-kilometer ($0.10 per vehicle-mile).
- If peak-hour speeds are under 65 kph (about 40 mph), the 1985 HCM speed-flow curves [for 96.6 and 80.5 kph (60 and 50 mph) operating conditions] can be used resulting in congestion costs of about $0.37 per vehicle-kilometer ($0.60 per vehicle-mile).

These are the congestion prices suggested by economic theory. However, because of the magnitude of the costs involved [daily charges of $1.00 to $6.00 per 16-km (10 mi) trip], downward adjustments may be needed in practice to minimize adverse impacts on the journey to work.

The practicality of implementing congestion pricing is another issue. Two important concerns must be addressed: (*a*) political acceptability and (*b*) a practical means of collecting tolls, that is, the technology issue. The first concern might be minimized by dedicating the collected revenues to highway transportation improvements. Use of improved automatic vehicle identification systems would probably address the technology issue.

Other key concerns that must be recognized include (*a*) possible shifts of traffic to city streets, thereby transferring problems; (*b*) encouragement of locational shifts in economic activity to the detriment of particular communities; and (*c*) clear definition of the extent and periods of operation. Finally, there is the equity issue —the cost of the journey to work would increase. This is particularly important in corridors where there is no viable public transportation alternative.

Consequently, other approaches may be more practical from a policy perspective, at least in the short run. These include (*a*) elimination of commuter discounts and possible institution of some form of congestion pricing on existing toll bridges, tunnels, and highways; (*b*) peak period parking surcharges; (*c*) land use controls that limit office developments away from transit corridors; and (*d*) ramp metering and related actions to reduce recurrent congestion. Finally, a program to eliminate key bottlenecks on urban freeways would further reduce the extent of congestion, and, in turn, the level of appropriate congestion charges.

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