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# Relation Between Optimum Congestion Tolls And Present Highway User Charges

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•THE MAIN PURPOSES of this paper are to develop some rough estimates of the optimum congestion toll structure for a large urban center such as the Twin Cities (Minneapolis-St. Paul, Minn.) Metropolitan Area and to provide some even rougher estimates of the costs that result from the inability and/or unwillingness to impose such tolls. Before proceeding, however, it seems a useful precaution to recognize the problem of fiscal irresponsibility that almost invariably plagues discussions of congestion pricing. Although space permits only partial resolution of the problem, establishing that a solution is possible at all seems worthwhile.

Those who support congestion pricing for highway systems rely heavily on the fundamental proposition of economic theory that efficiency in utilizing the resources available to an economy requires that the price of goods or services be set equal to the short-run marginal costs of producing them. The short-run marginal costs of highway trips are only indirectly related to the costs incurred by highway authorities; i.e., those of maintaining existing roads and of building new ones. The short-run marginal costs are almost entirely imposed on road users by the increase of vehicle operating and time costs of trips when roads are heavily congested.

The fact that the costs borne by highway authorities are not those which determine congestion tolls has led many economists and engineers to conclude that institution of congestion-based pricing would force abandonment of the time honored and presumably desirable practice of financing highway facilities entirely out of user charges. Consider, for example, the following comment:

> Since user fees limited in this way (i.e., to the difference between short-run marginal private and social costs) may not create total revenues sufficient to attract capital to highways and in limited cases may yield more revenues than could be invested efficiently in highways, the marginal cost pricing economists tend to deny that any relation, or close relation, should exist between user fees and capital investment. The rule of self-liquidation as a general guide to efficient investment is thrust aside as unnecessary and as a substantial hindrance to efficient utilization of existing highways. What specific rule for efficient road investment is to be substituted is far from clear; presumably it would be a matter for planning according to social surplus criteria of investment, often involving subsidy expenditures (1).

This and similar charges that fiscal irresponsibility is involved in advocating congestion pricing for highway services have been strongly refuted (2, 3).

The procedures a highway authority ought to use in establishing and pricing an optimum highway system are formally identical to the process through which the economist's "competitive market" reaches long-run equilibrium. In the short run, the price of a product in a competitive market will be equated with the short-run marginal costs of production. This price need not equal the product's average production costs. If it exceeds average production costs, new producers will be attracted to the industry, thereby expanding output and lowering price. Long-run equilibrium is reached when this process of entry equalizes product price and average production costs.

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To maximize the benefits derived from an existing road network, the highway authority must levy tolls equal to the difference between short-run marginal and average congestion costs. If the resulting toll collections are greater than the total costs of the system (including, it should be emphasized, an interest charge equal to the market rate of return on capital invested in the system), expanding the system, thereby lowering both average and marginal vehicle operating costs and hence optimum tolls, is in order. A long-run optimum highway network results if this process of system expansion and toll reduction is continued to the point where network costs (again, including the market return on invested capital) equal toll collections.

Strictly speaking, a long-run optimum highway system requires that tolls equal capital costs only if the production of highway services involves constant returns to scale. Some evidence is available that substantial scale economies exist in the provision of these services. If an activity involves increasing returns to scale, economic theory suggests the desirability of subsidizing that activity. That is, in the case at hand, theory dictates that the highway network ought to be expanded beyond the point at which congestion tolls just cover highway network costs.

## CHARACTERISTICS OF OPTIMUM CONGESTION TOLL STRUCTURE

The logical basis for establishing congestion tolls for highway use is the fact that the cost of a trip on a highway increases with the number of trips being taken on that highway. Specification of an optimum toll structure therefore requires quantification of the interrelationships among trip costs, traffic density, and highway characteristics. A representative vehicle operator's trip costs per mile may be written as

$$C = F(S, N, \bar{Z}) + V/S^{*}(S, N, \bar{Z}) \tag{1a}$$

in which V and $S^*$ are, respectively, the value he and his passengers place on an hour's travel time and the speed at which they actually travel; F includes all other trip costs; and S, N, and $\bar{Z}$ are, respectively, the vehicle operator's desired speed, traffic volume, and a set of such highway characteristics as the number and width of lanes, curvature and grade standards, and access controls. Of the costs summarized by F, reliable information is available only on gasoline and oil consumption and tire wear. Little if any data are available on such important subjects as the effects of highway characteristics, traffic volume, and desired speeds on the frequency and severity of accidents and on driver comfort and convenience. It seems reasonable to expect that both accident and comfort and convenience costs increase with traffic density and desired speed, but because no data are available, these costs are disregarded in the following discussion. This, it should be noted, imparts a downward bias to the estimated optimum tolls.

No market exists in which travel time is bought and sold, therefore, assigning a value to it is rather difficult. Indeed, the AASHO "Red Book" (4) seems to regard objective determination of the value of travel time to be impossible and, therefore, apparently assumes a number: "a value of travel time for passenger cars of \$1.55 per hour, or 2.59 ¢ per minute, is used herein as representative of current opinion for a logical and practical value" (4, pp. 103-4).

Even accepting this rather conservative value, travel time turns out to be by far the most important cost of urban travel. Therefore, it seems worthwhile to point out that a value of travel time is implicit in a driver's selection of a target speed. An increase in desired speed reduces the time costs of the trip. At the same time, however, an increase in speed increases vehicle operating and probably accident and comfort and convenience costs. Data in the "Red Book" (4, pp. 100-126) suggest that the following approximate costs per mile prevail for representative vehicles traveling on straight, level, paved rural roads where no traffic signals or stop signs exist to interrupt traffic flows:

$$\text{gasoline:} \quad \$0.30/(13.2 + 0.40S - 0.0076\,S^{2}) \tag{2a}$$

$$\text{oil:} \quad \$0.45/(1600 - 21S) \tag{2b}$$

$$\text{tires:} \quad \$0.0010 + 1.5 \times 10^{-8}\,S^{3.2} \tag{2c}$$

That is, on such roads, vehicle operating costs appear to be independent of traffic volume. On a very lightly traveled road where a driver can attain his desired speed, $S^* = S$ and Eq. 1a becomes

$$C = F(S, O, \bar{Z}) + V/S \qquad (1b)$$

It seems reasonable to suppose that a driver would attempt to travel at that speed which would minimize the total costs of his trip. Differentiating Eq. 1b with respect to S and setting the resulting expression equal to zero yields

$$V = S^2 \partial F/\partial S \qquad (3)$$

TABLE 1

TRAVEL TIME VALUES OF VEHICLE OCCUPANTS IMPLIED BY ALTERNATIVE DESIRED OPERATING SPEEDS

| Speed, S (mph) | $V = S^2 \frac{\partial F}{\partial S}$ (\$/hr) |
|---|---|
| 20 | -0.02 |
| 30 | 0.13 |
| 40 | 0.62 |
| 50 | 2.06 |
| 60 | 7.38 |
| 70 | 67.82 |

Regarding $F(S, O, \bar{Z})$ as equal to the sum of Eqs. 2a, 2b, and 2c, Table 1 gives the travel time values implied by Eq. 3 for representative values of S. If, as the "Highway Capacity Manual" (5, p. 32) indicates, desired speeds on high-quality, straight, level highways are approximately normally distributed with mean and standard deviation of 48.5 and 8 mph, respectively, $\bar{V}$, the mean travel time value for the occupants of all vehicles, can be obtained by evaluating

$$\bar{V} = \int_{-\infty}^{\infty} S^2 \frac{\partial F}{\partial S} n(S; 48.5, 8)\, dS \qquad (4)$$

This value is approximately \$3.00.

The analysis and the data underlying these estimates are, to say the least, rather rough. The true standard deviation is probably larger than that computed because (a) the average driver is only dimly aware of the relationship between speed and operating costs, and (b) few people drive average cars. However, the mean of the distribution would be over- or underestimated by these procedures only if the average driver's estimates of the relationship between speed and operating costs are biased. No evidence exists on the nature of these possible biases.

Inasmuch as data in the "Red Book" suggest that vehicle operating costs on rural roads are independent of traffic volume, if the hourly output of trips on a road is conceived of as a function of three variables, $N = g(T, C, \bar{Z})$, in which T is travel time, C is operating cost, and $\bar{Z}$ represents highway characteristics, $\partial N/\partial C$ is a constant. Hence, increased traffic affects the cost of a trip over a rural road (or an urban expressway) solely by increasing the time required.

Several studies on the relationship between N and T have been undertaken. To cite just a few, Greenshields (6) and Huber (7) found an approximately linear relationship between average speed and traffic density, D; i.e., the number of vehicles occupying a mile of road at any instant of time. For conditions of "free flow," Normann (8, 5, pp. 36-43), found speed and volume to be linearly related up to the "capacity" of the highway. Greenberg (9) and Underwood (10) found that relationships of the form $D = ae^{-bS}$ and $S = ae^{-bD}$, respectively, fit the data better than did linear relationships between S and D.

If volume equals density times "space mean speed," the total distance covered by all drivers divided by total time elapsed, and density equals volume times "space mean travel time," the reciprocal of "space mean speed," traffic volume and travel time can be related as follows:

$$\text{Greenshields:} \quad N = (aT - 1)/bT^2 \qquad (5a)$$

$$\text{Normann:} \quad N = (aT - b)/T \qquad (5b)$$

$$\text{Greenberg: } N = a/T\, e^{b/T} \tag{5c}$$

$$\text{Underwood: } N = (a + b \log T)/T \tag{5d}$$

Although the specific form of these relationships differs, all imply that the amount of time required per vehicle-mile increases with the number of trips being taken and that there is a maximum rate at which any given highway can produce vehicle-miles. If the rate at which people attempt to make trips exceeds this capacity level, the output of vehicle-miles actually falls.

These equations suggest that the addition of a vehicle to a traffic stream will increase total travel time in two ways: (a) the occupants of the vehicle will incur travel time costs that they would not have experienced had they not chosen to make their trip, and (b) by adding to the level of congestion on the highway, the additional vehicle increases the travel times of all the remaining drivers. The marginal cost of a trip (i.e., the increase in total costs associated with an additional trip, or the decrease in costs associated with elimination of a trip) can be written

$$\frac{\partial(N\bar{V}T)}{\partial N} = \bar{V}T + N\bar{V}\frac{\partial T}{\partial N} \tag{6}$$

in which $N\bar{V}T$ is the total hourly time cost of all vehicle-miles and $\bar{V}T$ is the cost incurred by occupants of the additional vehicle; the remaining term is the cost this additional vehicle imposes on the other vehicles in the traffic stream.

The basic argument made for setting congestion tolls is that in their absence individual drivers would consider only the $\bar{V}T$ component of Equation 6. By ignoring the $N\bar{V}\ \partial T/\partial N$ component, they would tend to make trips of less value than the total cost. Only if each driver were required to pay a toll equal to $N\bar{V}\ \partial T/\partial N$ would he limit trips to those with values in excess of their costs.

Assuming the mean desired operating speed on high-quality, straight, level rural highways to be 48.5 mph (5, p. 32), the Greenshields, Normann, and Underwood relationships can be rearranged to yield the following relationships:

| | Travel Time per Veh-Mi, T | Marginal Minus Avg. Time per Veh-Mi, (N dT/dN) | |
|---|---|---|---|
| Greenshields: | $\alpha T^2 = 0.0825\,T - 0.0017$ | $T(48.5\,T - 1)/(2 - 48.5\,T)$ | (7a) |
| Normann: | $(48.5 - 18.5\,\alpha)\,T = 1$ | $T(48.5\,T - 1)$ | (7b) |
| Underwood: | $\alpha T = 3.88 + \log T$ | $17.84\,\alpha T^2/(1 - 17.84\,\alpha T)$ | (7c) |

in which $\alpha$ is the volume-capacity ratio, the ratio of actual trips per hour to the maximum number of trips per hour the highway can produce. The Normann relationship assumes also an average speed of 30 mph when a highway is used to capacity level.

The specific values for marginal and average travel times per vehicle-mile implied by these relationships vary substantially with differing volume-capacity ratios (Table 2). In all cases, the marginal travel times per vehicle-mile increase rapidly with increases in volume-capacity ratios. However, under conditions of uninterrupted flow, this effect can be ignored when determining operating costs if, as the "Red Book" suggests, vehicle operating and accident costs depend on desired rather than on realized speeds. The differences between marginal and average travel times per vehicle-mile given in Table 2 can therefore be converted into optimum tolls per mile simply by multiplying by an appropriate travel time value (Table 3).

The preceding discussion has been based on uninterrupted traffic flows of the sort that prevail on high-quality rural highways and urban freeways. Analysis of such flows is simple in comparison to the problems involved in dealing with urban arterial

TABLE 2

AVERAGE AND MARGINAL MINUS AVERAGE TRAVEL TIMES[a]

| Volume-Capacity Ratio, $\alpha$ | Travel Times (min/mi) | | | | | |
|---|---|---|---|---|---|---|
| | Greenshields | | Normann | | Underwood | |
| | Aver. | Marginal Minus Aver. | Aver. | Marginal Minus Aver. | Aver. | Marginal Minus Aver. |
| 0.1 | 1.27 | 0.04 | 1.28 | 0.05 | 1.28 | 0.05 |
| 0.2 | 1.30 | 0.07 | 1.34 | 0.11 | 1.34 | 0.11 |
| 0.3 | 1.36 | 0.15 | 1.40 | 0.18 | 1.40 | 0.20 |
| 0.4 | 1.41 | 0.23 | 1.46 | 0.26 | 1.47 | 0.30 |
| 0.5 | 1.46 | 0.31 | 1.53 | 0.36 | 1.55 | 0.45 |
| 0.6 | 1.51 | 0.39 | 1.60 | 0.47 | 1.66 | 0.69 |
| 0.7 | 1.57 | 0.59 | 1.69 | 0.61 | 1.80 | 1.07 |
| 0.8 | 1.69 | 0.96 | 1.78 | 0.77 | 1.98 | 1.75 |
| 0.9 | 1.90 | 2.22 | 1.88 | 0.99 | 2.26 | 3.42 |

[a]From Greenshields, Normann, and Underwood travel time relationships.

TABLE 3

ESTIMATED HIGHWAY USER TOLL

| Volume-Capacity Ratio | Estimated Toll (¢/mi) | | | | | |
|---|---|---|---|---|---|---|
| | Travel Time Value = $1.55/Veh-Hr | | | Travel Time Value = $3.00/Veh-Hr | | |
| | Greenshields | Normann | Underwood | Greenshields | Normann | Underwood |
| 0.1 | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 | 0.2 |
| 0.2 | 0.2 | 0.3 | 0.3 | 0.3 | 0.5 | 0.5 |
| 0.3 | 0.4 | 0.5 | 0.5 | 0.8 | 0.9 | 1.0 |
| 0.4 | 0.6 | 0.7 | 0.8 | 1.2 | 1.3 | 1.5 |
| 0.5 | 0.8 | 0.9 | 1.2 | 1.5 | 1.8 | 2.3 |
| 0.6 | 1.0 | 1.2 | 1.8 | 1.9 | 2.4 | 3.4 |
| 0.7 | 1.5 | 1.6 | 2.8 | 3.0 | 3.0 | 5.4 |
| 0.8 | 2.5 | 2.0 | 4.5 | 4.8 | 3.9 | 8.8 |
| 0.9 | 5.7 | 2.6 | 8.8 | 11.1 | 4.9 | 17.2 |

streets. The characteristics of traffic flows on arterials vary from complete congestion in the queues that form behind stop signs and red traffic lights, through an intermediate stage as vehicles accelerate to normal operating speeds on leaving these impediments, to the free-flow characteristics that correspond to the existing traffic volume as modified by whatever speed limits may be enforced. The characteristics are also affected by the frequency of right- and left-turn maneuvers, the amount of pedestrian traffic at intersections, the amount of curb parking, the number and spacing of bus stops and signals, and (but only for low traffic volumes) the sequencing of red and green cycles at successive traffic lights.

Few systematic studies have been undertaken of the interrelationships among volume, density, and travel time on urban arterial streets, and only one of these provides information that can be analyzed in a fashion similar to that employed with the Greenshields, Normann and Underwood relationships for rural roads and urban freeways. Coleman (11) fitted quadratic relationships to data on travel time-volume-capacity ratios observed on a sample of one- and two-way streets in several Pennsylvania cities. These relationships and the implied differences between marginal and average travel times are:

$$\text{One-way streets: } N/C = \alpha = -1.98 + 1.07\,T - 0.096\,T^2 \quad (8a)$$

$$NdT/dN = \alpha\,(1.07 - 0.192\,T)^{-1} \quad (8b)$$

TABLE 4

AVERAGE AND DIFFERENCE BETWEEN MARGINAL AND AVERAGE MINUTES PER VEHICLE-MILE ON ONE- AND TWO-WAY URBAN ARTERIAL STREETS

| Volume-Capacity Ratio | Time per Mile (min) | | | |
|---|---|---|---|---|
| | One-Way Streets | | Two-Way Streets | |
| | Aver. | Marginal Minus Aver. | Aver. | Marginal Minus Aver. |
| 0.1 | 2.51 | 0.17 | 2.52 | 0.18 |
| 0.2 | 2.68 | 0.36 | 2.70 | 0.38 |
| 0.3 | 2.87 | 0.58 | 2.89 | 0.60 |
| 0.4 | 3.07 | 0.83 | 3.10 | 0.87 |
| 0.5 | 3.28 | 1.14 | 3.32 | 1.19 |
| 0.6 | 3.52 | 1.53 | 3.57 | 1.59 |
| 0.7 | 3.80 | 2.05 | 3.84 | 2.13 |
| 0.8 | 4.12 | 2.86 | 4.19 | 3.00 |
| 0.9 | 4.54 | 4.52 | 4.62 | 4.79 |

Two-way streets: $N/C = \alpha = -1.90 + 1.02\,T - 0.090\,T^2$ (9a)

$NdT/dN = \alpha\,(1.02 - 0.180\,T)^{-1}$ (9b)

By definition, traffic volume is maximum when the volume-capacity ratio is one. The fitted relationships had maximum volumes at volume-capacity ratios of 0.904 and 1.067 for one- and two-way streets, respectively. Accordingly, the volume-capacity ratios implied by the listed formulas are, respectively, 1/0.904 and 1/1.067 times those of the computed regression relationships. The computed relationships implied mean speeds of 25.5 and 47.4 mph for the one- and two-way streets, respectively, at zero traffic volumes. The latter value clearly seems too high. For this reason the two-way street travel time values (Table 4) implied by the preceding equations are 1.08 min per mile greater than those indicated by the computed relationships.

As with rural roads, the difference between marginal and average time costs varies substantially with the volume-capacity ratio. For both one- and two-way streets, an additional trip when volume is 70 percent of capacity increases the aggregate travel time of other vehicles by approximately 3.5 times that at 30 percent of capacity. The ratio is more than 25 to 1 when comparing operation at 90 percent with operation at 10 percent of capacity.

In the Chicago Area Transportation Study, both vehicle operating and accident costs for a trip segment were negatively related to the average speed for the segment (12, Table 5). From data given in Tables 4 and 5, the accident and operating cost component of optimum congestion

TABLE 5

CHICAGO AREA TRANSPORTATION STUDY SPEED-RELATED COST PARAMETERS

| Speed (mph) | Cost (¢/mi) | | |
|---|---|---|---|
| | Operating | Accident | Total |
| 5 | 4.80 | 6.75 | 11.55 |
| 10 | 3.69 | 4.25 | 7.94 |
| 15 | 3.10 | 2.70 | 5.80 |
| 20 | 2.78 | 1.80 | 4.58 |
| 25 | 2.57 | 1.15 | 3.72 |
| 30 | 2.41 | 0.80 | 3.21 |
| 35 | 2.36 | 0.55 | 2.91 |

TABLE 6

COSTS IMPOSED ON OTHER DRIVERS BY ADDITIONAL VEHICLE-MILE ON TWO-WAY URBAN ARTERIAL STREETS AND DERIVED OPTIMUM TOLL

| Volume-Capacity Ratio | Imposed Costs (¢/mi): Marginal Minus Aver. Operating and Accident Costs | Imposed Costs (¢/mi): Marginal Minus Aver. Time Costs At \$1.55[a] | Imposed Costs (¢/mi): Marginal Minus Aver. Time Costs At \$3.00[b] | Optimum Toll (¢/mi): At \$1.55 (Col. 1 + Col. 2)[a] | Optimum Toll (¢/mi): At \$3.00 (Col. 1 + Col. 3)[b] |
|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) |
| 0.1 | 0.2 | 0.5 | 0.9 | 0.7 | 1.2 |
| 0.2 | 0.5 | 1.0 | 1.9 | 1.5 | 2.4 |
| 0.3 | 0.8 | 1.5 | 3.0 | 2.4 | 3.8 |
| 0.4 | 1.1 | 2.2 | 4.3 | 3.4 | 5.5 |
| 0.5 | 1.5 | 3.1 | 5.9 | 4.5 | 7.4 |
| 0.6 | 2.0 | 4.1 | 7.9 | 6.1 | 9.9 |
| 0.7 | 2.5 | 5.5 | 10.7 | 8.0 | 13.2 |
| 0.8 | 3.3 | 7.8 | 15.0 | 11.1 | 18.3 |
| 0.9 | 4.7 | 12.4 | 24.0 | 17.1 | 28.8 |

[a]Assuming travel time value of \$1.55/hr.
[b]Assuming travel time value of \$3.00/hr.

tolls (i.e., the difference between marginal and average operating and accident costs, NdC/dN) can be estimated (Table 6). Considering operating and accident costs per vehicle-mile a function of operating speed or C = f(S), and noting that, for two-way streets, NdT/dN = $\alpha/(1.02 - 0.180\,T)$, NdC/dN can be written

$$N\frac{dC}{dN} = N\frac{dC}{dS}\frac{dS}{dT}\frac{dT}{dN} = -\frac{1}{T^2}\frac{\alpha}{(1.02 - 0.18T)}\frac{dC}{dS} \qquad (9c)$$

The relationship between these optimum tolls and current highway user charges can be estimated at least roughly. Federal and state excises on gasoline, averaging about 10¢ a gallon, comprise the only appreciable source of tax revenue varying directly with vehicle mileage.

On rural roads and urban freeways, the 48.5-mph driver of one of the "Red Book's" average cars would average 14.7 mi per gal and hence would pay a toll of approximately 0.7¢/mi. Assuming alternative average travel time values of \$1.55 and \$3.00 per vehicle-hour, such a driver would be paying optimum tolls at respective volume-capacity ratios of approximately 40 percent and 30 percent. At lesser volume-capacity ratios he would be paying more than the costs his trips impose on other drivers. At greater volume-capacity ratios, his trips would, in effect, be subsidized by society.

The average operating speeds underlying the city street toll estimates (Table 6) range from 13 to 24 mph at volume-capacity ratios of 90 and 10 percent, respectively. At these speeds in city traffic, one study (13) determined average gasoline consumption for a 1951 6-cylinder car to be 14 and 18 mi/gal, respectively. At the same average speeds, Eq. 2a suggests gasoline consumption rates of 17 and 18 mi/gal, respectively, or an actual tax burden of 0.5 to 0.7 ¢/mi. Even assuming the "Red Book" estimate of travel time values to be correct, Table 6 suggests that these tax rates would be optimum only for city street volume-capacity ratios of less than 10 percent. Registration fees of, for example, \$20 per passenger vehicle per year would add 0.4 and

0.1 ¢/veh-mi to the respective tax costs of 5,000- and 20,000-mi/yr drivers, raising total city street tax payments to 0.6 to 1.2 ¢/veh-mi. Even assuming $1.55 to be the correct travel time valuation, this greater tax rate would be the appropriate toll for a city street volume-capacity ratio of less than 20 percent.

## SOCIAL COSTS OF PRESENT USER CHARGES

Because the use made of both rural and urban highway networks varies substantially through time, optimum user charges also vary through time. As is indicated in Table 7, approximately 70 times as many passenger cars (or their congestion equivalents in trucks and buses) are operated on the highways of the Twin Cities Metropolitan Area between 4:30 and 5:00 p.m. as during the early morning hours. At a value for travel time of $3.00 per vehicle-hour, an optimum toll of almost 20¢/veh-mi is suggested for the afternoon peak as compared to 0.2¢ for the early morning period. Even at the "Red Book's" $1.55 per vehicle-hour travel time valuation, the peak half-hour optimum toll is on the order of 50 times that during the early morning hours. The tolls of 1¢/veh-mi imposed by current gasoline taxes and license fees fall far short of the costs of most weekday trips in this area. Inasmuch as current user fees are more than sufficient to pay for current urban highway maintenance and construction programs, Table 7 suggests that an expanded highway construction program would be in order. Indeed, the relationships developed previously and existing levels of highway use imply rates of return on new freeway construction in the area of as much as 300 percent.

TABLE 7

ESTIMATED OPTIMUM TOLLS FOR TWIN CITIES METROPOLITAN AREA

| Half Hour Beginning | Aver. Traffic Density[a] (1,000 veh) | Optimum Toll (¢/mi) | |
|---|---|---|---|
| | | At $1.55/hr[b] | At $3.00/hr[b] |
| 12:00 m | 7.4 | 0.9 | 1.4 |
| 12:30 a.m. | 5.0 | 0.8 | 1.3 |
| 1:00 | 3.9 | 0.5 | 0.8 |
| 1:30 | 2.5 | 0.3 | 0.5 |
| 2:00 | 1.4 | 0.2 | 0.3 |
| 2:30 | 1.1 | 0.2 | 0.2 |
| 3:00 | 1.0 | 0.2 | 0.2 |
| 3:30 | 0.9 | 0.2 | 0.2 |
| 4:00 | 1.4 | 0.2 | 0.3 |
| 4:30 | 1.8 | 0.3 | 0.4 |
| 5:00 | 3.0 | 0.3 | 0.5 |
| 5:30 | 5.9 | 0.7 | 1.2 |
| 6:00 | 17.3 | 2.0 | 3.3 |
| 6:30 | 33.5 | 4.0 | 6.5 |
| 7:00 | 48.3 | 6.1 | 9.9 |
| 7:30 | 69.4 | 9.1 | 16.1 |
| 8:00 | 51.9 | 6.6 | 10.8 |
| 8:30 | 40.3 | 4.9 | 8.0 |
| 9:00 | 45.6 | 5.6 | 9.2 |
| 9:30 | 42.2 | 5.1 | 8.2 |
| 10:00 | 52.6 | 6.7 | 11.0 |
| 10:30 | 44.1 | 5.4 | 8.8 |
| 11:00 | 50.0 | 6.3 | 10.2 |
| 11:30 | 48.1 | 6.0 | 9.8 |
| 12:00 noon | 42.6 | 5.2 | 8.6 |
| 12:30 p.m. | 41.4 | 5.0 | 8.2 |
| 1:00 | 52.0 | 6.6 | 10.9 |
| 1:30 | 45.8 | 5.6 | 9.2 |
| 2:00 | 49.3 | 6.2 | 10.1 |
| 2:30 | 46.6 | 5.8 | 9.5 |
| 3:00 | 52.5 | 6.7 | 11.0 |
| 3:30 | 55.0 | 7.1 | 11.6 |
| 4:00 | 59.6 | 7.8 | 12.8 |
| 4:30 | 76.9 | 11.5 | 19.1 |
| 5:00 | 73.2 | 10.6 | 17.6 |
| 5:30 | 52.7 | 6.7 | 11.0 |
| 6:00 | 45.1 | 5.3 | 8.7 |
| 6:30 | 35.3 | 4.2 | 6.8 |
| 7:00 | 40.0 | 4.9 | 8.0 |
| 7:30 | 34.8 | 4.2 | 6.7 |
| 8:00 | 33.4 | 4.0 | 6.5 |
| 8:30 | 28.9 | 3.4 | 5.6 |
| 9:00 | 27.9 | 3.3 | 5.4 |
| 9:30 | 21.8 | 2.6 | 4.2 |
| 10:00 | 16.3 | 1.9 | 3.2 |
| 10:30 | 12.7 | 1.5 | 2.4 |
| 11:00 | 11.6 | 1.4 | 2.2 |
| 11:30 | 8.6 | 1.0 | 1.6 |

[a] For the period July 8 to Dec. 1, 1958.
[b] Travel time value per vehicle-hour.

Although at an average travel time valuation of $3.00 per vehicle-hour, a toll of 19¢/veh-mi is suggested for afternoon rush hour traffic volumes, Table 7 does not imply that it would be desirable to charge such a toll even if it were possible to do so. If the price of peak-hour trips were increased, it seems reasonably safe to assert that the number of trips taken during the peak hour would decline. Some trips currently made then would not be taken at all, others would be shifted to off-peak hours, and still others would be consolidated. An increase in peak-hour tolls would provide a powerful stimulus toward the formation of more car pools and would quite likely lead a larger number of employers to institute staggered work hours.

If it is safe to assume that an increase in peak-hour tolls would lead to a reduction in peak-hour trips, then some of those who are currently making these trips

place values on them that are less than their total costs. Thus, inability and/or unwillingness to vary user charges with the demand for trips involves a definite and perhaps substantial social cost. Determination of the magnitude of this social cost would require data on the degree to which an increase in the price of peak-hour trips would reduce their number. Unfortunately, the required data do not exist. It is possible, however, both to suggest the nature of the problem in somewhat greater detail and to draw some inferences about the orders of magnitude that may be involved.

Consider, therefore, the following simple situation. A 1-mi stretch of super highway connects two points, Here and There. The vehicle operating and time costs of a trip over this road, C, depend on the ratio of the rate at which vehicles are making trips, Q, to the capacity of the highway, Z. For 12 hr of the day the demand for trips is relatively high; for the remaining 12 hr the demand is relatively low. In both peak and off-peak periods, the number of trips taken is a function of the "price" of a trip; i.e., the vehicle operating and time costs involved plus whatever toll is imposed.

It seems reasonable to regard the net benefit of trips over this road as the sum of the prices individual travelers would pay for them minus both the total vehicle operating and time costs they incur and the costs of providing the road. Ignoring maintenance costs and assuming that constant returns to scale are involved in constructing roads, this latter cost component can be written as rkZ, in which r and k are the interest rate of relevance in valuing highway investments and the capital cost of a unit of highway capacity, respectively. This net benefit can be written as

$$B \equiv \int_0^N F(Q)\, dQ + \int_0^n f(q)\, dq - NC(N/Z) - nC(n/z) - rkZ \qquad (10)$$

in which F(Q) (f(q)) is the price that the taker of the Qth (qth) peak (off-peak) period trip would pay for it and N and n are the actual number of peak and off-peak period trips, respectively.

A beneficent highway authority would presumably want to maximize this expression by varying the toll (or tolls) charged for trips and the capacity of the highway. If different tolls can be charged for the two time periods, the benefit maximizing conditions can be found by differentiating Eq. 10 with respect to N, n, and Z, or

$$\frac{\partial B}{\partial N} = F(N) - C(N/Z) - N\frac{\partial C}{\partial N} = 0 \qquad (11a)$$

$$\frac{\partial B}{\partial n} = f(n) - C(n/Z) - n\frac{\partial C}{\partial n} = 0 \qquad (11b)$$

$$\frac{\partial B}{\partial Z} = \frac{\partial C}{\partial (N/Z)}\frac{N^2}{Z^2} + \frac{\partial C}{\partial (n/Z)}\frac{n^2}{Z^2} - rk = 0 \qquad (11c)$$

According to Eqs. 11a and 11b, to maximize benefits the "price" paid by the Nth (nth) traveler should equal the marginal cost of his trip. Inasmuch as each traveler pays the vehicle operating and time costs of his trip, C(N/Z) and C(n/Z), the "price" of the trip will equal its marginal cost only if peak and off-peak tolls equal, respectively, to $N\,\partial C/\partial N$ and $n\,\partial C/\partial n$ are charged. According to Eq. 11c, increments in capacity should be provided up to the point where the last increment yields vehicle operating and time cost savings just equal to its capital cost.

Eqs. 11a, b, and c can be rearranged to demonstrate the validity of the basic contention that optimum congestion tolls would just suffice to cover the capital costs of an optimum highway. Multiplying Eq. 11 through by Z yields the following expression for the total capital costs of an optimum facility:

$$rkZ = \frac{\partial C}{\partial (N/Z)}\frac{N^2}{Z} + \frac{\partial C}{\partial (n/Z)}\frac{n^2}{Z} \qquad (12)$$

in which $\frac{\partial C}{\partial (N/Z)} \frac{N}{Z}$ is the optimum peak period toll for the facility. A similar expression results for the off-peak period toll. Total toll collections can be obtained simply by multiplying the peak and off-peak tolls by peak and off-peak traffic levels; that is,

$$\text{Total tolls} = \frac{\partial C}{\partial (N/Z)} \frac{N^2}{Z} + \frac{\partial C}{\partial (n/Z)} \frac{n^2}{Z} \tag{13}$$

But the right-hand side of Eq. 13 equals the right-hand side of Eq. 12; i.e., optimum tolls just equal the capital costs of an optimum facility.

Even if the highway authority cannot charge different tolls during peak and off-peak periods, it would still presumably want to adjust highway capacity to satisfy Eq. 11 and to set that single toll which comes as close as possible to maximizing total benefits. That is, it would presumably want to establish a toll such that

$$\frac{\partial B}{\partial T} = \frac{\partial B}{\partial N}\frac{\partial N}{\partial T} + \frac{\partial B}{\partial n}\frac{\partial n}{\partial T} = 0 \tag{14}$$

The changes in benefits resulting from changes in the number of peak and off-peak period trips are given by Eqs. 11a and 11b, respectively. The effect of a change in the toll on peak period trips can be obtained by noting that F(N) = T + C(N/Z). Differentiating this expression with respect to T gives

$$\frac{\partial F}{\partial N}\frac{\partial N}{\partial T} = 1 + \frac{\partial C}{\partial N}\frac{\partial N}{\partial T}, \quad \text{or} \quad \frac{\partial N}{\partial T} = \left(\frac{\partial F}{\partial N} - \frac{\partial C}{\partial N}\right)^{-1} \tag{15}$$

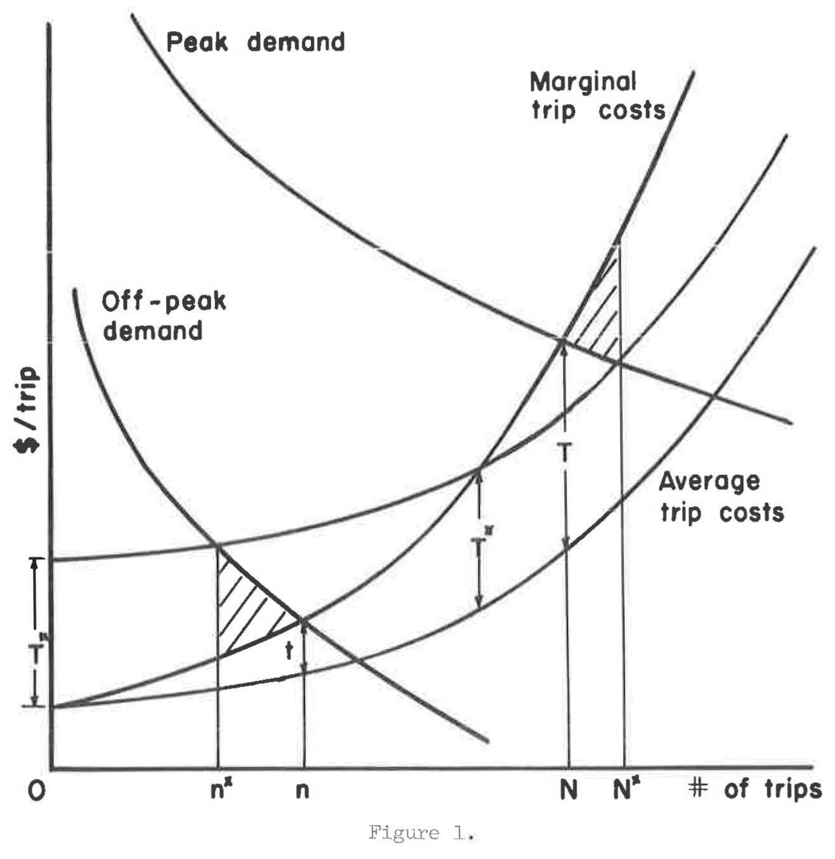


Figure 1.

Off-peak period trips may be treated similarly. Considering T* the best single toll, Eqs. 11a, 11b, 14, and 15 imply that this toll must satisfy the condition

$$\frac{T^* - N\frac{\partial C}{\partial N}}{\frac{\partial C}{\partial N} - \frac{\partial F}{\partial N}} + \frac{T^* - n\frac{\partial C}{\partial n}}{\frac{\partial C}{\partial n} - \frac{\partial f}{\partial n}} = 0 \tag{16}$$

i.e., that T* ought to be set somewhere between the optimum peak and off-peak hour tolls.

Figure 1 provides a graphic illustration of the problem. Tolls of T and t resulting in N and n trips in the peak and off-peak periods, respectively, maximize the benefits to be derived from the highway. If only a single toll is possible, greater than and fewer than the optimum number of trips would be taken in the peak and off-peak periods, respectively. That is, during the off-peak period, an additional n - n* trips could be taken having values greater than their costs. The loss of benefits involved in not allowing these trips to be made is represented by the lower shaded area. Similarly, during the peak period N* - N trips would be made involving values less than their costs. The upper shaded area represents the loss of benefits involved in these additional trips. How large these two benefit losses would be depends on the elasticities of the two demand curves and the distance between them, as well as on the elasticity of the vehicle operating and time costs relationship. The smaller the difference between peak and off-peak hour demands and the more nearly perpendicular these demand relationships are, the smaller will be the loss in benefits resulting from charging a single toll. The loss in benefits will also be smaller the more nearly horizontal the C (Q/Z) relationship is.

In principle, the difference between the maximum benefits attainable on the road between Here and There when variable tolls are and are not charged can be estimated by substituting demand and cost relationships in Eqs. 10 through 16. Unfortunately, even the quite simple travel time-volume-capacity relationships lead to formidable computational problems. The benefit estimates summarized in the following were therefore based on an even simpler relationship between volume-capacity ratios and vehicle operating and time costs:

$$C(Q/Z) = 6.2¢ + bQ/Z \tag{17}$$

in which 6.2¢ is the travel time cost per mile of the occupants valuing their time at $3.00 an hour traveling in a vehicle at 48.5 mph. Vehicle operating costs are ignored on the assumption that these costs are independent of volume-capacity ratios on rural roads and urban freeways. Two alternative values of b (3.8¢ and 6.2¢) were employed. The former value derives from the Highway Capacity Manual's estimate (5, p. 32) that the average speed on a high-quality rural road is 30 mph at a volume-capacity ratio of 1. The latter value is based on Greenshield's implication that average travel time at a volume-capacity ratio of 1 is double that at a volume-capacity ratio of zero.

Analysis of highway department construction estimates suggests that the average cost of four-lane urban expressways in Minnesota is approximately $1.2 million per mile (14). If such a highway has a capacity of 7,200 vph and if the interest rate appropriate to valuing highway investments is 10 percent, the hourly cost is approximately 0.2¢ per unit of freeway capacity (i.e., per vehicle-mile per hour).

For computational ease, linear demand as well as linear cost relationships was assumed in the benefit calculations. That is, both the peak and the off-peak demand relationships assumed were of the form P = C - DN, in which P is the price (the toll plus the time costs) at which N trips would be made. For each of the two cost functions, benefit calculations were made for nine pairs of demand relationships. The specific parameter values used (Table 8) were chosen to reflect differences both within and between periods in demand elasticities and differences between demand levels in peak and off-peak periods.

TABLE 8

SPECIFIC PARAMETER VALUES FOR BENEFIT COMPUTATIONS

| Peak Period Demand | | Off-Peak Demand | | Group Numbers |
|---|---|---|---|---|
| C | D | C | D | |
| | | | 0.00004 | A1, D1 |
| 0.2 | 0.00002 | 0.1 | 0.00002 | A2, D2 |
| | | | 0.00001 | A3, D3 |
| | | | 0.00040 | B1, E1 |
| 2.0 | 0.00020 | 1.0 | 0.00020 | B2, E2 |
| | | | 0.00010 | B3, E3 |
| | | | 0.00040 | C1, F1 |
| 2.0 | 0.00020 | 0.1 | 0.00020 | C2, F2 |
| | | | 0.00010 | C3, F3 |

TABLE 9

OPTIMUM TOLL ON HYPOTHETICAL FREEWAY

| Group | Toll Type[a] | Optimum Toll (¢/mi) | | |
|---|---|---|---|---|
| | | Subgroup 1 | Subgroup 2 | Subgroup 3 |
| (a) Time Cost per Mile = 6.2¢ + 3.8¢ x volume/capacity | | | | |
| A | T* | 0.83 | 0.72 | 0.70 |
| | T | 1.18 | 1.15 | 1.08 |
| | t | 0.18 | 0.32 | 0.51 |
| B | T* | 0.87 | 0.80 | 0.84 |
| | T | 1.16 | 1.07 | 0.86 |
| | t | 0.28 | 0.52 | 0.83 |
| C | T* | 0.79 | 0.61 | 0.42 |
| | T | 1.19 | 1.19 | 1.19 |
| | t | 0.01 | 0.02 | 0.05 |
| (b) Time Cost per Mile = 6.2¢ + 6.2¢ x volume/capacity | | | | |
| D | T* | 1.05 | 0.91 | 0.87 |
| | T | 1.50 | 1.47 | 1.38 |
| | t | 0.23 | 0.40 | 0.63 |
| E | T* | 1.10 | 1.01 | 1.07 |
| | T | 1.48 | 1.37 | 1.09 |
| | t | 0.36 | 0.66 | 1.05 |
| F | T* | 1.02 | 0.77 | 0.54 |
| | T | 1.52 | 1.52 | 1.52 |
| | t | 0.02 | 0.03 | 0.06 |

[a]T*, T, and t are, respectively, the optimum single toll, the optimum peak period toll, and the optimum off-peak toll for highways of optimum size.

In Table 8, groups A, B, and C were distinguished from groups D, E, and F in that, for the former set, the more elastic cost curve was assumed in the benefit computations. That is, the computations for these groups were made under the assumption that the slope of the average time cost curve was 3.8¢, whereas those for the latter group assumed it to be 6.2¢. Speaking roughly, groups A and D and the remaining groups involve relatively elastic and inelastic peak period demands, respectively. The ratios of off-peak to peak demands are relatively high for groups B and E and relatively low for groups C and F. Finally, within each of the alphabetical groups, subgroups 1, 2, and 3, respectively, involve highly elastic, moderately elastic, and inelastic off-peak demand schedules.

Initially, two sets of benefit computations were undertaken for each of these 18 subgroups. First, the hypothetical authority in charge of the hypothetical highway was allowed to vary the size of the highway but was constrained to establish only a single toll applicable to both time periods. The toll-highway size combination that maximized net benefits was determined. Next, the authority was allowed to levy different tolls on peak and off-peak users. The benefit maximizing combination of tolls and highway size was again found. Net benefits as defined by Eq. 10 were computed under both pricing systems.

The optimum single tolls developed in this fashion ranged from 0.4 to 1.1¢, the highest tolls generally being associated with the highest ratios of peak to off-peak hour demand elasticities. When the authority was allowed to vary tolls between periods, the optimum peak period tolls ranged from 0.9 to 1.5¢/veh-mi. In this case, the highest tolls were associated with the highest ratios of peak to off-peak period traffic.

These toll estimates seemed reasonable enough. However, several of the remaining conclusions were rather surprising. First, the hypothetical authority designed highways that seemed to be considerably more lavish than those currently being built. Whereas current urban expressway design standards call for peak-hour volume-capacity ratios of 70 to 80 percent, the hypothetical authority's

highways all had peak period volume-capacity ratios in the 20 to 30 percent range. Second, the optimum single-toll highways were only 0.1 to 3 percent larger than their two-toll counterparts rather than substantially larger, as had been expected. Third, and most surprising, the inability to vary tolls with highway demand had practically no effect on maximum attainable highway benefits. The ratio of single-toll to two-toll net benefits ranged from 99.6 to 99.9999 percent.

TABLE 10

SUBSIDY REQUIRED TO MAXIMIZE BENEFITS IF A SINGLE TOLL IS LEVIED

| Group | Subsidy | | |
|---|---|---|---|
| | Subgroup 1 | Subgroup 2 | Subgroup 3 |
| A | 0.77 | 0.72 | 0.77 |
| B | 0.88 | 0.89 | 0.99 |
| C | 0.67 | 0.51 | 0.37 |
| D | 0.76 | 0.71 | 0.74 |
| E | 0.87 | 0.89 | 0.99 |
| F | 0.67 | 0.52 | 0.37 |

An important qualification should quickly be added here. The revenues derived from optimum variable tolls on an optimum highway system would just cover the capital costs of that system. However, the general principle easily can be established that the revenues from benefit maximizing single tolls will fall short of the capital costs of any optimum highway system, and a subsidy will be necessary, if the elasticity of the off-peak demand for trips is equal to or greater than that of the peak demand. Inasmuch as the bulk of peak-hour trips are work trips, there is probably considerably less elasticity during this period than at off-peak hours when the demand is for pleasure, shopping, and other trip purposes. Because this proved true in the cases studied, maximizing benefits while charging a single toll required subsidizing the highway. In the most extreme cases, the subsidy amounted to almost two-thirds of the highway's total cost (Table 10).

These unanticipated results suggested that two further possibilities are worthy of exploration: (a) that these results would not hold for highways with design volume-capacity ratios more nearly equal those presently being built; (b) that they would not hold if the highway authority were forced to be self-supporting. Time did not permit exploring this latter possibility. As for the former, a final set of benefit computations was run in which the size of the highway was restricted to levels that would yield peak period volume-capacity ratios of 60 to 80 percent. These restrictions reduced maximum possible benefits by as much as 10 to 15 percent, increased optimum peak period tolls to the 3 to 4.5¢ range, and made the highway self-supporting even when a single toll was charged. However, the ratios of maximum possible benefits in the one- and two-toll cases were still uniformly in excess of 99 percent.

## CONCLUSIONS

It is, of course, redundant to say that the results obtained from the foregoing analysis depend on the assumptions made and that these assumptions may be grossly unrealistic. Still, it seems reasonable to hazard two fundamental generalizations:

1. Inasmuch as congestion tolls of more than 6¢/veh-mi are associated with the traffic levels prevailing during the greatest part of the day, current gasoline and vehicle license taxes aggregate to only about 1¢/veh-mi, and these taxes appear more than adequate to cover current highway construction and maintenance programs, it seems reasonably safe to assert that the present highway network of the Minneapolis-St. Paul area, and probably most other major urban centers, is grossly underdeveloped.
2. A considerable social loss is unquestionably involved in current highway utilization patterns. The fact that user charges do not vary with the demand for highway services undoubtedly contributes to this loss. However, the apparent inadequacy of present urban highway networks may well be of far greater importance.

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# Theory of Spillover Cost Pricing

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•THE SUBJECT of this paper, a theory of highway finance, derives from a collision between growth of population and a structure of production which is built upon geographical concentration. Underlying the problem is rapid development of certain technologies and relative lag in others, with the result being congestion—a differential in rates of performance. The paper examines an economic theory that derives from the problem where a spillover cost will denote the congestion of one highway user by another, where the relevant cost is loss of time and general nuisance. The text of the argument is a mathematical examination of assumptions to the proposition that highway prices (user taxes, tolls, etc.) should exceed the cost of maintaining highways, and exceed the cost for purpose of reducing the public use of such highways, a thesis recently identified with the work of British economist Walters (1). It is concluded that assumptions underlying the proposition are too improbable to serve as a foundation for public policy involving disposition of $13 billion annually, the current expenditure for highways in the United States. That Walters' thesis may be a reasonable one in light of other assumptions is beside the point of the examination, which has the purpose of considering the assumptions of his thesis for what they are. The argument pertains to a fixed highway plant which is invariably the result of industrial concentration.

## THE MARGINAL COST CONTROVERSY

The problem under discussion is of interest to both the economist and the engineer, but the weakness in this alliance has been a failure of communication between the parties. Many engineers look upon highway prices as means of raising revenue or covering cost, whereas economists look upon prices mainly as rationing devices and, as Valavanis (2) observed, "only secondarily as means of raising revenue or covering costs."

By "short-run marginal (physical) cost" the economist, when considering highways, means the increase in highway maintenance and other physical costs resulting from another unit of traffic during a period—assuming full maintenance of the capital outlay. Hence, accrual for periodic resurfacing and major repair, as the accounts are treated by (engineers) Baker et al. (3), would enter the marginal cost account, whereas snow removal by comparison might not. The precise treatment of costs associated with soil failure, washout, restrained temperature warping stress (and weather in general) is not obvious.

It is instructive to note, however, that the concept of marginal cost had its origin in 18th century soil mechanics. One authority (4), for instance, determined marginal cost of a given wheel load to be "one-fourth in amount as the width of the tire is doubled," a radical measure for the time that was adopted by the State of New York (5) in 1836 for the purpose of setting highway tolls. As early as 1773 service on British turnpikes was being priced according to logical engineering methods based on such damage factors as wheel load, tire width, and horsepower (6). (For the first important American turnpike see Ref. 7.) That these early "models" are still more sophisticated than typical prescriptions (versions of the so-called ton-mile theory (8)) in use among the American states today is acknowledged. But it was from this humble origin that the theory of marginal cost as a principle of resource allocation burst

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upon the world through the imagination of French engineer Dupuit (9), who is the father of welfare economics as later developed by Marshall (10) and by other writers employing the techniques of Pareto (11).

It is the principle of marginal cost that market price should be equal to the change in cost with respect to another unit of output. Consequently, there is in principle no accommodation for the recovery of any accountable cost such as wages or rents. The only counterpart of a marginal cost is a rate of change which acts not unlike a brake upon the path of production. Increase of output in one direction is restrained by a factor (price) equal in value to the input lost for use in some other direction, with the result that resistance is equalized among all paths of production at the margin. The result is perfectly consistent with either loss or profit. And in particular, the theory of marginal cost has nothing to do with the recovery of full cost which, depending upon cost functions and level of output, may be the same as, less than, or greater than total revenue (12). The economist is only seldom concerned with the history of production; he is inconsiderate of overhead cost, which he considers to be "sunk"; and he commands an imposing theoretical machinery for moving about large chunks of humanity with the aid of two or three simplifying assumptions. If all fails, he invokes a head tax. But he is seldom concerned with that which is "sunk."

It is emphasized, however, that the basic ingredient to early experiments with marginal cost pricing was the obvious relationship between traffic and destruction, whereas given this relationship at the time, when

> . . . a heavy wagon [was] the most efficacious machine that the art of man, in its present state of science, could construct for grinding to powder the materials of our roads (13),

the policy maker faced no conceptual problem in his treatment of overhead cost because the highway was conveniently destroyed by the traffic it was designed to serve.

## THE PARADOX OF OVERHEAD COST

With the introduction of modern concrete pavement, however, the economist was confronted by a more subtle relationship because, like many other materials, concrete has a fairly well-defined limiting unit stress below which millions of repetitions of stress will not cause the material to fail. Under specified conditions it is possible to describe a set of relationships that would be consistent in principle with zero marginal cost or, worse still, negative marginal cost, for when stress from load is less than limiting unit stress, the repetition of stress is "actually beneficial and strengthens the concrete" (14, 15). These suggestions are contained in modern analysis of materials.

But the problem for the economist was evident enough by 1923 for Clark (16) to frame his famous "paradox of overhead cost":

> Here the paradox of overhead cost assumes an extreme form. Before a road is built, it is rational to say that the traffic which benefits should bear the overhead cost and that if it cannot bear it, the outlay is probably not justified. But once a well-paved road is built, reasonable use costs nothing at all, and any charge which limits the amount of such traffic would result in unused capacity and the loss described by the phrase 'idle overhead.'

Conversely, if charges were set equal to the cost of reasonable use, total revenue would be less than total cost because reasonable use costs nothing at all, just the reverse of the early highway problem. Such is the paradox. It must be added, however, that solving the problem of "excess capacity" on an isolated feeder road would only increase congestion in the trunkline, the problem of "chasing rainbows" in terminology of engineers.

But the problem was apparently resolved by Hotelling (17), who in 1938 demonstrated that "everyone can be made better off" under a policy of effectively no user taxes at all. The overhead cost might be recovered through an income or head tax.

Resulting controversy (18) involving "second best" solutions is not dealt with here, although the rationale of the Hotelling thesis is examined later on. Related theory under general treatment of public utilities is found in a paper by Montgomery (19).

The engineer could not help but reply, however, that careful inspection of Hotelling's resolution indicates the solution of a paradox without a paradox to resolve. To measure excess capacity as conceived by J. M. Clark, one must first have a measure of highway capacity simpliciter. Yet the latter is merely a generic term relating to the ability of a roadway to accommodate traffic (20) so that without additional information, one can only assert, for example, that the "capacity" of a modern two-lane highway is in some sense any value one may care to select between, say, 10 and 2,000 motorcars per hour. But if one may adopt any value within this range, how shall he determine a unique value for purposes of defining excess capacity which is a factor in producing the paradox of overhead cost? Indeterminacy would suggest the need for at least an additional relationship.

This relationship is found, of course, in average traffic speed, which is an index of quality of service and which varies inversely with number of vehicles per hour or, in Clark's terminology, the "amount of traffic." Consequently, any charge which "limits the amount of such traffic" will result in better service, an improvement which Clark identified, in effect, with the creation of "unused capacity and the loss described by the phrase, 'idle overhead.'" But if such is the case, the highway problem is now reversed because "excess capacity" is the very product which consumers demand, a shift anticipated by Pigou (21, 22, 23) in his treatment of congestion prior to Hotelling's rehabilitation of Dupuit. This brings one to the present period of the marginal cost controversy.

## THE PARADOX OF SPILLOVER COST

Accordingly, it has been argued by Walters (1) and others that the proper price for highway service will be the sum of the short-run marginal (physical) cost and the consumer spillover cost, which jointly constitute the social marginal cost. Under the paradox of overhead cost it was assumed that, in any case, the charge for highway service would not exceed average total physical cost—or simply unit cost—as allocated during a period. But this assumption is now in doubt, presenting the policy maker with a new "paradox" in highway finance. Before a road is built, to paraphrase Clark, it has been reasonable to think that the charge for service should approach (total) unit cost as an upper limit. But once a road is built the spillover cost of its use during a period may exceed the revenue from charges equal to unit cost during the period, in which case any charge which fails to exceed total physical cost will result in resource misallocation. It has been convenient to think that roads were subsidized when user assessments failed to meet full cost. It will now be less convenient to think that roads are subsidized when assessments fail to exceed full cost. Such are the subtleties of economic analysis.

## PURE THEORY OF SPILLOVER COST PRICING

It is in order to inquire of the theory underlying the spillover cost solution. Imagine an economy of m consumers, each of whom supplies homogeneous labor (or resources) and exists upon a diet of highway travel and some other composite good so that the utility function, U, of the jth consumer ( $j = 1, 2, \ldots, m$) might take the form

$$U_j = U_j(x_j, y_j, z_j; x_1, \ldots, x_{j-1}, x_{j+1}, \ldots, x_m) \tag{1}$$

in which $x_j$ denotes the number of vehicle trips of defined length made by the jth consumer during a period; $y_j$, the units of the composite good consumed; and $z_j$, the units of labor (or resources) supplied by the jth consumer during the same period, assuming that

$$\frac{\partial U_j}{\partial x_i} \begin{Bmatrix} > \\ < \end{Bmatrix} 0 \text{ for } \begin{Bmatrix} i = j \\ i \neq j \end{Bmatrix} \quad i, j = 1, 2, \ldots, m \tag{2}$$

while

$$\frac{\partial U_j}{\partial y_j} > 0 > \frac{\partial U_j}{\partial z_j} \tag{3}$$

within the range of the argument where it is also assumed that if the consumer were to lose successive units of one good, he would require in exchange even greater increments of the other good in order to remain just as well off ($dU_j = 0$) as before, the standard convexity premise.

It is also assumed that the consumer will act so as to maximize the value of Eq. 1 subject to the income barrier

$$z_j w - x_j p_x - y_j p_y = 0 \tag{4}$$

in which w denotes wage (income) per unit of labor (resources); $p_y$, the price of the composite good per unit; and $p_x$, the cost or price of a vehicle trip—the cost to the consumer, which includes vehicle expenses, and may or may not include a highway toll or tax, but does not include a factor for the cost of time and congestion which is rather treated under the form of Eq. 2 for $i \neq j$. It is assumed that $p_x$, $p_y$, and w are constant—the same for all consumers—and regarded as parameters by the consumers who are to operate homogeneous vehicles, use homogeneous fuel, provide homogeneous labor and, in general, to live in a state of pure competition as defined by the textbooks. Accordingly, one can form the function

$$U_j^* = U_j (x_j, y_j, z_j; x_1, \ldots, x_{j-1}, x_{j+1}, \ldots, x_m) + \gamma_j (z_j w - x_j p_x - y_j p_y) \tag{5}$$

and set its partial derivatives equal to zero

$$\frac{\partial U_j^*}{\partial x_j} = \frac{\partial U_j}{\partial x_j} - \gamma_j p_x = 0 \tag{6}$$

$$\frac{\partial U_j^*}{\partial y_j} = \frac{\partial U_j}{\partial y_j} - \gamma_j p_y = 0 \tag{7}$$

$$\frac{\partial U_j^*}{\partial z_j} = \frac{\partial U_j}{\partial z_j} + \gamma_j w = 0 \tag{8}$$

$$\frac{\partial U_j^*}{\partial \gamma_j} = z_j w - x_j p_x - y_j p_y = 0 \tag{9}$$

giving the necessary conditions for a maximum value of Eq. 5, in which $\gamma_j$ is the Lagrange multiplier—defined as the change in utility with respect to income for the jth consumer who, since he has no control over the traffic of others, will regard

$$x_1, \ldots, x_{j-1}, x_{j+1}, \ldots, x_m \tag{10}$$

as parameters and increase highway travel to the point where utility derived from another trip is equal to the cost of the trip

$$\frac{\partial U_j}{\partial x_j} = \gamma_j p_x \tag{11}$$

with the same being "true" for all consumers so that, in general, one obtains

$$\frac{p_x}{p_y} = \frac{\partial U_j/\partial x_j}{\partial U_j/\partial y_j} \qquad j = 1, 2, \ldots, m \tag{12}$$

all of which may be derived from Eqs. 6 and 7 and the relevant assumptions. Because Eq. 12 is consistent with any form of human behavior, the second-order conditions for a maximum of Eq. 5 are baroque, unless the jth consumer is disposed to mistake happiness for misery. In any case, one does not assume that the consumer will take into account the congestion he imposes upon others.

Such capacity for role taking could be ascribed only to a larger fiduciary having a welfare function, W, on the order of

$$W = W(U_1, U_2, \ldots, U_m) \tag{13}$$

which might take any form, say

$$W = U_1 + U_2 + \ldots + U_m \tag{14}$$

depending on the sentiments of the fiduciary who, in any case, would be restrained by a production barrier which, given

$$X = x_1 + \ldots + x_m; \; Y = y_1 + \ldots + y_m; \; Z = z_1 + \ldots + z_m \tag{15}$$

might take the form

$$Z - Z(X, Y) = 0 \tag{16}$$

in which minimum aggregate amount, Z, of labor required to produce the social product is stated as a function of the aggregate product produced (and consumed) during a period. Suppose the case in which the fiduciary wished to maximize some given form of Eq. 13 subject to Eq. 16. Then a maximum value would be sought

$$W^* = W\Big[U_1(x_1, y_1, z_1; x_2, \ldots, x_m) \ldots, U_m(x_m, y_m, z_m; x_1, \ldots, x_{m-1})\Big] + \varphi[Z - Z(X, Y)] \tag{17}$$

the partial derivatives of which are set equal to zero

$$\frac{\partial W^*}{\partial x_j} = W_j \frac{\partial U_j}{\partial x_j} + \sum_{\substack{i=1 \\ i \neq j}}^{m} W_i \frac{\partial U_i}{\partial x_j} - \varphi Z_x = 0 \tag{18}$$

$$\frac{\partial W^*}{\partial y_j} = W_j \frac{\partial U_j}{\partial y_j} - \varphi Z_y = 0 \tag{19}$$

$$\frac{\partial W^*}{\partial z_j} = W_j \frac{\partial U_j}{\partial z_j} + \varphi = 0 \tag{20}$$

$$\frac{\partial W^*}{\partial \varphi} = Z - Z(X, Y) = 0 \tag{21}$$

$$j = 1, 2, \ldots, m$$

yielding the necessary conditions for a maximum value of Eq. 17 and in which $\varphi$ is the Lagrange multiplier and $\partial W/\partial U_j$ is denoted by $W_j$ and $\partial Z/\partial X$ by $Z_x$, etc.

By replacing the summand or spillover cost factor in Eq. 18 by $S_j$ and, considering only the center group of terms in Eqs. 18 and 19, these are rearranged so as to bring the correlative assertion into view

$$\frac{\partial U_j/\partial x_j}{\partial U_j/\partial y_j} = \frac{\varphi Z_x - S_j}{\varphi Z_y} \tag{22}$$

in which the Lagrange multiplier expresses the change in social utility with respect to labor; $Z_X$ (etc.) expresses the change in labor, Z, with respect to X; and $S_j$ expresses the change in social utility with respect to the congestion created by another vehicle trip—with the result that all terms are reducible to social utility or, more precisely, to the utility or welfare of the fiduciary who is assumed to have elected Eq. 14 as the form of his own utility function.

Accordingly, it follows under the rationale of Eq. 12 that the fiduciary will select a new set of market prices ($r_X$, $r_y$) for units of X and Y so that

$$\frac{r_x}{r_y} = \frac{Z_x - S_j/\varphi}{Z_y} \tag{23}$$

the right side of which is now expressed in units of labor and is equivalent (in terms of labor) to Pigou's solution (18)

$$\frac{\text{Producer's Marginal Cost X + Consumer's Spillover Cost X}}{\text{Producer's Marginal Cost Y}} = \frac{\text{Marginal Social Cost of X}}{\text{Marginal Social Cost of Y}} \tag{24}$$

assuming pure competition and absence of all side effects except the presence of $S_j$, for which it is also assumed that

$$S_1 = S_2 = \ldots = S_m \tag{25}$$

in which the value of $S_j$ is negative in sign by Eq. 2 for $i \neq j$. For the special case $S_j = 0$ relating to the "wide road" of Pigou, which is very wide, and where the price of road service exceeds the money value of $Z_X$ ($= w\ Z_X$) by some amount attributed to overhead cost, the paradox of overhead cost is obtained in terms of Eq. 23. If this difference is removed by setting $r_X = w\ Z_X$, the solution identified with Hotelling is obtained. For the present case in which $S_j \neq 0$ (but negative in value) and

$$r_x = w(Z_x - S_j/\varphi) \quad ; \quad r_y = w(Z_y) \tag{26}$$

it follows that the market value of goods produced will exceed the income from production, indicating the need of a negative head tax (subsidy) in order to exhaust the product.

Will a small railroad obtain the same subsidy as a large trucking firm with or without a utility function? The subsidy cannot be permitted to vary with use of highways because the consumer might discount the road price by the amount of the subsidy and, apart from some time preference, go about his business as before. Will a small railroad without a utility function obtain the same subsidy as a consumer with or without a motorcar? Will trucks be required to pay for congesting themselves? Will trucks be required to pay for congesting the motorcar after trucks have purchased sufficient additional road space to permit the motorcar to travel at the same rate before and after

the injection of trucks (according to the incremental cost theory of the Bureau of Public Roads)? It has always been obvious that the theory of pure competition posed a threat to the General Motors Corporation, but never quite so obvious as at the present.

But other and subversive properties of the toll theory remain to be considered and pertain to its operational status simply as a matter of conception apart from feasibility which, at this level of precision, is rather beside the point. Going back to Eq. 19 and, considering only the center group of terms, rearrange these so as to bring the following into view

$$W_j \frac{\partial U_j}{\partial y_j} = \varphi Z_y \qquad j = 1, 2, \ldots, m, \tag{27}$$

for which, by assumption of Eq. 14,

$$W_1 = \ldots = W_j = \ldots = W_m = 1 \tag{28}$$

so that Eq. 27 becomes

$$\frac{\partial U_1}{\partial y_1} = \ldots = \frac{\partial U_m}{\partial y_m} = \varphi Z_y \tag{29}$$

which, in conjunction with Eq. 7, yields

$$\gamma_1 = \ldots = \gamma_m \tag{30}$$

the assertion that marginal utility of income must be identical for all consumers in order to maximize welfare of the fiduciary. The marginal utility of trips must be identical for all consumers; the marginal utility of composite good, identical; the marginal (dis)utility of labor, identical; and the marginal utility of income must be identical for all consumers in order to maximize welfare of the fiduciary. Welfare of fiduciary approaches its maximum as human differences approach zero and, at the optimum, vanish—yielding a theory of welfare with the property of human variation factored out.

If these results are too extreme, one may select another explicit form for the welfare function. But let there be no mistake about the issue. Until a given form of Eq. 13 is adopted, the theory of tolls is short as many equations as the number of consumers minus one. Advocates of the theory can appraise many features of their system but not the feature at issue (i.e., welfare). It will also be obvious that specification of Eq. 13 embraces implications that transcend any theory of highway prices.

Other problems for the policy maker may be noted. It is not true that labor receives the value of its marginal product as strictly required by the theory; not true that prices are equal to marginal cost as required by the theory; not true that producers are too small to affect the price; not true that commodities are homogeneous, and so on. But, in general, it is not true that the American economy will satisfy the assumptions of the theory of spillover cost pricing. And if it will not, it simply will not, a negation made explicit by Chamberlin (24).

It will also be obvious that one cannot eschew the assumptions of the model under an argument where the test of the model is power of prediction. No prediction is involved. The assumptions are the thing.

Of course, some stringent features of the model might be relaxed with gains in empirical correspondence by the introduction of an "efficiency unit" for labor, thus relaxing the homogeneity assumption for labor, and permitting wages (say per hour) to vary with "efficiency." But precisely what shall be relaxed and what shall be held firm? How will assumptions not relaxed appear to our sense of logical balance in the absence of assumptions that are relaxed? For instance, according to the rationale of

Eq. 23, the only remaining problem for the policy maker is to summarize the findings expressed for this purpose in units of labor by Eq. 23. But will a unit of labor paid $60 an hour in the production of commercial advertisement count the same as a unit of labor paid only $3 an hour in the production of primary education? Given the "efficiency unit," the answer may be that a unit in commercial advertisement should count 20 (= 60/3) times as much as a unit in primary education—the rationale being that abandonment of homogeneity postulate for labor does not involve abandonment of assumption that factors of production receive the social value of their marginal product. But the problem at this point is too obvious. The policy maker might even reply that assumptions underlying the proper price for highway service are a greater social liability than the traffic.

There is finally a problem of theoretical discretion. Perhaps in a free society (and a wealthy one), what is done may not prove to be so important as the reasons given for what is done. Consumers are to be charged for the time delays they cause each other according to the magnitude of $S_j$. But as St. Clair has remarked, it is like "adding insult to injury first to recognize that time delay is a cost to the consumer, and then to say that he must pay, in order to maximize his own benefits, a tax that will cause the cost to leap from the average to the marginal point."

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# Optimum Investment in Two-Mode Transportation Systems

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Proposals have been raised to tax use of highways in relationship to the volume of vehicles thereon. Aside from mechanics and legal questions, this raises the problem of methods of financing all means of transportation (for example, whether, as a matter of public policy, road users might be taxed to support rapid transit). Beyond this, the question of public investment in (or taxation of) transportation facilities is raised as it may affect property values; for example, in hastening the obsolescence of buildings. These are difficult questions, related both to public goals and to democratic and practical means for implementing them. The paper discusses these problems from the viewpoint of the transportation planner and the city planner.

• PROPOSALS have been made to tax the use of expressways so that higher taxes would be paid on more congested roads, or at more congested time periods on a given road (14). These proposals are based on the assumption that it is proper to take a limited view of one road at a time and to treat that facility as a monopolistic production apparatus whose profit should be maximized, or whose use should be held below some predetermined level by some pricing mechanism.

This narrow viewpoint cannot be taken by those whose business it is to make recommendations for transportation improvements for metropolitan areas. For such work it is obvious that consideration of gains and losses must be as complete as possible. For example, reductions in accidents in a broad band of a city resulting from the construction of an expressway is a demonstrated gain which should be taken into account in preparing plans (15). Congested use of expressways, although more costly to all users of expressways, may be at a per mile cost level substantially below that of travel on arterial and local streets, and hence may provide over-all reductions in cost to the whole community (16).

It would appear that pricing of transportation facilities ought not to be considered without a simultaneous or even prior consideration of the costs and benefits of supplying new transportation facilities. And this investigation ought to consider the various types of new facilities which should be provided. This, in turn, calls for a basic understanding of the selection of mode of travel by persons living in urban areas.

This paper, therefore, addresses itself to the problem of investment in transportation facilities, both for individual and group modes of transportation. (Throughout this paper "individual" transportation is treated as synonymous with automobile transportation; "group" transportation is used for so-called "mass transportation"—that is, buses, rail rapid transit, and suburban railroads.) This is a problem of intense interest to planners. An investigation of optimum investment policies produces insights which will be helpful in considering appropriate policies for the taxation or pricing of transporta-

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tion. The question of maintenance and management (or control) of existing transportation facilities is not considered, other than through taxation or pricing, and this latter is only discussed at the end of this paper. Furthermore, the scope of this paper is restricted to the transportation of persons within urban regions by individual and group modes of transportation.

The "investment problem" assumes that a metropolitan society and its nation or state has a surplus of funds available for investment. This investment may be either in capital facilities or in the form of subsidies for the continued operation of some service. The transportation investment problem is the problem of deciding:

1. How much investment should be made in transportation, as opposed to other possibilities for investment, either public or private.
2. What mode (that is, bus, rail rapid transit, or road system) should receive investment funds, and in what proportion.
3. When the investment should be made.
4. Where the investment should be made.

The transportation investment problem is made more difficult by the fact that it is a geographic as well as a financial problem. The buying and selling of transportation services (for example, the seat-mile of bus service or the vehicle- or seat-mile of automobile service) is accomplished over the surface of large metropolitan regions and not in the non-dimensional (and non-existent) "perfect market." Clearly, the facts of space and spatial distribution affect the investment problem. Also, there is the problem of skillful design: a given level of investment in roads can be profitable or unprofitable depending on the skill with which it is laid out. This calls for a team approach (using both economists and planner-engineers) both in studying investment and in planning the facilities.

The remainder of the paper develops an approach for the examination of this question. This is done by first studying a series of goal systems: those of the transportation user, those of the land-based entrepreneur, and those of metropolitan management. Next, the user's viewpoint is examined, both as to the amount of transportation purchased and as to the type of transportation selected. Then the investment problem is analyzed from the viewpoint of metropolitan management and, finally, conclusions are reached.

## GOALS

It is assumed that there are three sets of goals: those of the user of transportation, those of persons in their land-based activities, and those of metropolitan management. "Metropolitan management" assumes a top level metropolitan, or perhaps state, viewpoint. Naturally, these sets of goals are not separable in real life because the land-based entrepreneur is also a traveler, and in both capacities he is a voter influencing metropolitan management.

### The Transportation User

The goal of the transportation user is taken to be economic: to minimize the sum of his transportation costs in relationship to the reward he will obtain from traveling.

Transportation is viewed as a cost item. The costs include money outlay (transit fares, auto and truck operating costs, vehicle ownership costs, etc.), time outlay, the risk of accidents, and discomfort of various types. Only rarely is urban transportation per se undertaken as a reward in itself—about 1 percent of all trips are "ride" trips (1)—hence, the cost viewpoint is reasonable.

Obviously people do not expend money, time, risk, or discomfort unless they hope to gain a return. The rewards of traveling lie in the gains to be made at the destination of each trip, and include such things as wages and salaries, and recreational or residential satisfactions. These will be different in amount for different people and will vary by trip purpose. Over time these gains and satisfactions may be expected to rise, as long as productivity continues to rise.

Travel is seen, then, as a cost item to be expended for a return of some type. For example, a person will spend more (travel farther) for a good job than he will for a

lower paying one, and he will travel farther to purchase a sofa than a loaf of bread. Naturally, the length of each type of trip is also a function of the locational patterns of various enterprises, which in turn is affected by the economics of production and distribution.

## The Site User

The person undertaking some activity on a particular site—a retailer in his store, a manufacturer in his plant, a housewife at home—has the same basic goal as the person in motion but it is expressed differently. The goal is to maximize gains, whether they be the profits of commercial and industrial activity or the satisfactions of residential or recreational activity.

The site user's gains include such things as wages and salaries, residential and recreational satisfactions, profits from business and industry, and the possession of goods purchased at a site. These gains come whether the person is a permanent site user (for example, an owner or renter) or a temporary site user (for example, an employee or customer).

The site user's costs include such things as labor costs, material costs, taxes, money paid for goods or services purchased on the site and, of course, transportation costs of all types.

For the site user to maximize his gains he must first choose a site and then manage it or do business at it or work on it or live on it. The site selection process is a complex calculus of alternate site costs, taxes, community services, environment, location with respect to market or labor force, and transportation costs. Site occupancy involves decisions on investment in buildings, grounds and equipment, how to get ahead on one's job, what goods to purchase, and so on.

An important point here is the relative importance of transportation costs to all other costs of the site user. Probably transportation costs are not less than 10 percent, and rarely more than 25 percent of all costs, irrespective of whether the activities are residential, recreational, or employment activities. The non-transportation costs (and, by the same token, the rewards) are dominant. This is another way of saying that land use is a primary consideration which should be served by transportation facilities.

The much greater importance of the site-based costs and returns relative to those of transportation leads to the selection of densities of land development which will permit the site user to maximize his gains. For example, a long assembly-line building may be extremely profitable because it reduces labor costs, which are a high proportion of manufacturing costs. Travel requirements may be increased, due to the need to find a site large enough, but the over-all operation may become more profitable, even counting increased travel costs. Similarly, congestion in a wide area of a city may be a necessary price to pay for greater social productivity.

## Metropolitan Management

The goal of metropolitan management is, broadly speaking, a social welfare goal: to maximize the metropolitan "product." (It might be desirable to add "and to insure an equitable distribution of the metropolitan product." However, distributional equity is beyond the scope of this paper.) In this instance "product" is construed to be broader than the traditional economic definition of the total goods and services produced. Maximization of product requires satisfaction of the demands and needs of the urban society for services, creation of an environment (or arena) in which the production of goods and services will be maximized, and promotion of the general health, safety, welfare, and amenity. Inevitably there are conflicts within these goals and, like the transportation user and the site user, metropolitan management must strike a balance between competing goals in order to optimize net gains to the entire community.

Without having perfect knowledge, or comprehensive understanding of all the factors, or the ability to account for all gains and losses, those who represent this viewpoint must be as careful and complete as is possible in the accounting they use in making decisions on investment.

The difficulty is that for a metropolitan investment, such as an expressway, the re-

turn may, like the bread cast on the proverbial waters, come in a myriad of ways at different, unpredictable future times. Investment selection is further complicated by the interdependent character of investment decisions both spatially and over time. One metropolitan investment will often call forth additional investments in related facilities and services; or the reaction to a metropolitan investment may, over time, create the need for an additional investment. Thus, provisions of a municipal water supply to a suburban area may, in the absence of other controls or actions, generate sufficient density of development to require municipal sewers and eventually new arterial streets. Clearly, each action of metropolitan management cannot be evaluated alone but must be accounted within a large enough reference to include interaction between items and over time and to include private or mixed as well as strictly public actions.

For the purposes of this paper, various sets of goals which together comprise the main goal of metropolitan management have been categorized. For convenience, these have been drawn up into two main parts—those connected with transportation and all other goals—as follows:

Non-transportation goals:

1. Increase in per capita production of goods and services, including housing.
2. Equitable distribution of social product.
3. Amenity.
4. Reduction of capital and operating costs of building and sites.
5. Increase in public knowledge of factors influencing development decisions.

Transportation goals:

6. Satisfaction of sum total of travelers' objectives (for example, to minimize travel time, costs, risks, and discomfort in relation to gains from travel).
7. Reduction of capital and operating costs of road and transit systems.
8. Satisfaction of other transportation objectives (for example, goods movement).

In addition, metropolitan management must aid individual decision making by increasing public knowledge of the potential effects of both public and private action in transportation and in the non-transportation areas. Also, it must inform the public of the range of alternative actions and their probable effects.

## Viewpoint of Paper

The viewpoint of this paper is that of metropolitan management, and the focus is on transportation investment. Metropolitan management wants to decide how much to invest, what mode should receive what proportion, and when and where.

In making these decisions, metropolitan management assumes that travelers will seek to maximize the returns to be achieved from their daily expenditures in transportation. Put in other words, metropolitan management understands that, given the more stable and dominant locations of land-based activities, travelers will seek to minimize their transportation costs, each person freely seeking to minimize his own costs. A clear understanding of how the traveler's goal affects the purchase of travel is therefore necessary and is considered in a subsequent section.

The viewpoint of metropolitan management is necessarily long-range—that is, 20 to 30 years. In a period of this length, metropolitan management realizes that real wealth will substantially increase.

It is assumed that investment funds of some magnitude are available. Within such a time period, the accounting of gains and costs will be as complete as possible.

Metropolitan management is vitally concerned with the goals of site users—that is, with their desire to increase gains. Increasing site user gains, is, in the aggregate, the same as increasing the production of goods and services for the metropolitan community. This has been assumed as the single criterion for success in governmental policies.

To achieve this goal, metropolitan management has a variety of tools—taxation, spending, land control and regulation, and the intangible power of persuasive leadership. Transportation investment is among these tools. The problem, however, is that the effect of the single variable, transportation, on goods production, amenity and so forth, is difficult to ascertain. This paper does not consider explicitly the effect of transpor-

tation investment on non-transportation goals. Each year additional technical gains in the planning and decision making processes are being made; and it is hoped that gains will be made in considering non-transportation goals, just as it is hoped that this paper will provide a systematic way of evaluating the proper allocation of investment as between individual and group transportation.

## CHOICE OF TRANSPORTATION MODE

In this section, the choice of mode of transportation is investigated from the viewpoint of the user, who is basically assumed to be an economic man in his choice of mode of transportation.

In order to treat choice of mode on the basis of cost analysis, the user is assumed to have good knowledge of vehicle costs, of operation and depreciation, and a knowledge of the time required to travel by the various modes of travel which are available. Tangible but immeasurable costs of travel, such as discomfort and inconvenience, are assumed to be incorporated with time as a cost. Thus the inconvenience of waiting at a station or stop for a group form of transportation is included within over-all journey time. Time in all cases throughout this analysis is taken as portal-to-portal time, and speeds are taken as journey speeds, which are considerably slower than vehicle speeds, inasmuch as they allow for walking, waiting, and parking. (It should be noted, however, that in the subsequent section on "Selection of Capital Investment Policy," in dealing with person-miles of travel some speeds used in computation are the speeds actually experienced on an express facility).

Because the authors take a long-run view of the life of a transportation facility, it follows that a long-run view should be taken in analyzing the costs of transportation when seen from the viewpoint of the user. Specifically this refers to a period lengthy enough to enable the user to exercise the option of whether or not to purchase an individual vehicle (automobile). In this analysis therefore, car depreciation and insurance are included in calculating transportation costs.

Throughout this analysis, the unit "person-mile of transportation" (PMT) is used. The use of this unit permits comparison of costs as between individual and group forms of transportation.

The costs of purchasing person-miles of transportation, by whatever mode, are composed of two parts: (a) movement costs and (b) time costs. Movement costs consist of fares in the case of group transportation. Fares may or may not cover all the costs of producing group transportation service; that is, of operating buses, subway trains, elevated trains, or suburban railroad trains. Nevertheless, they are the costs apparent to the user, and are the costs which he sees in making a decision as between modes. Movement costs in individual transportation include the costs of owning, operating, and insuring an automobile seat for one person. (If mean occupancy is 1.5 persons per vehicle, then vehicle-miles of travel costs are divided by 1.5 to obtain person-miles of travel costs.) Both movement and time costs are treated in the following.

### Movement Costs

Although this paper is primarily concerned with developing improved methods for analysis and investment planning, these methods require some real measures, both to test reasonableness and in actual planning. It is in this sense only that the values given herein are used.

An urban situation was visualized in establishing preliminary working figures of transportation costs encountered by the user.

1. Both \$0.15 and \$0.25 fixed fares, without additional transfer costs, are assumed for buses and rail rapid transit (subway or elevated lines).
2. A charge of \$0.04 per mile is assumed for suburban railroad service.
3. Auto costs, at an average speed of 11 mph (implying driving under conditions of some congestion), are assumed as follows:

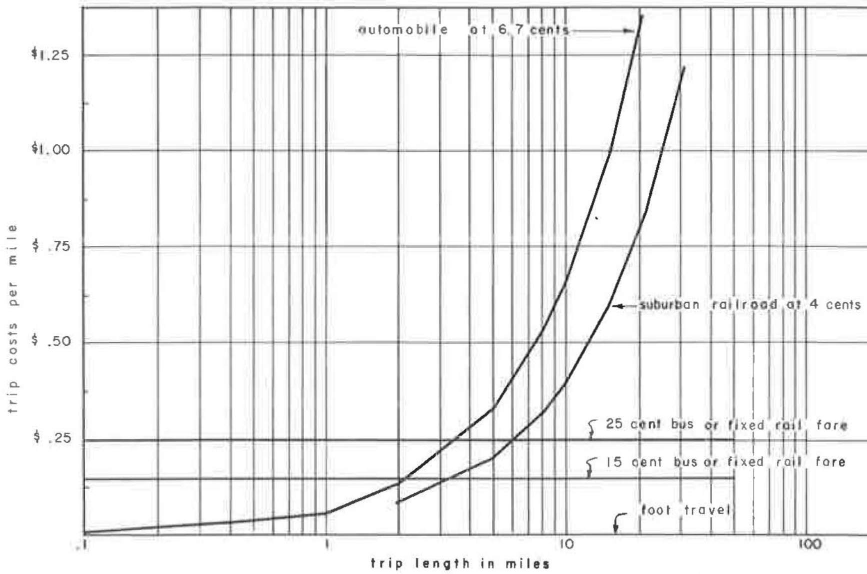


Figure 1. Comparative movement costs per person-trip by trip length and mode.

| Item | Cost ($0.01/mi) |
|---|---|
| Variable cost (2): | |
| (a) Gas, oil, tires, brake wear, maintenance | 4.41 |
| Fixed cost (3): | |
| (b) Depreciation | 2.54 |
| (c) Insurance, registration, titling | 1.49 |
| (d) Parking, garaging | 1.08 |
| Total | 9.52 |

This can be rounded off to $0.10 per mile, which for average occupancy at 1.5 persons per car, makes the per person costs $0.0667 per mile.

Figure 1 shows how trip costs rise when a person increases the length of a particular journey. Of course, if the purchase of round trip or daily journeys is considered, the price of the fixed-fare group transportation would have to be doubled or more, inasmuch as separate fares are required for each leg of a journey. Because it is not possible to consider the use of rapid transit or suburban railroad service for very short distances, Figure 1 does not portray these costs below 1- and 2-mi limits, respectively.

If these were the only considerations associated with selecting the amount and mode of transportation, the following points could be made:

1. All trips would be made on foot.
2. The next cheapest form of transportation would vary as a function of trip length:
   (a) Trips less than 2 mi long would be made by automobile (suburban railroads presumably would not be available for short journeys).
   (b) Trips between 2 and 3 mi in length would be made by suburban railroad.
   (c) Trips more than 3 mi in length would be made by bus or by rail rapid transit.

These points would be altered slightly depending on the cost figures used and the number of riders per car, but they do show that movement costs are not the only things considered by persons when choosing mode of transportation. Otherwise something more than the 28 percent of all trips now made on foot or the 6½ percent of trips to work on foot would be the rule (4). Granted the employment, recreation, shopping, and other opportunities which are spread over a modern metropolitan area, the person

who walks barely has time to reach most of them on foot. Certainly he will have little time left over to participate in them. Because participation in these activities is rewarding, a person is generally willing to spend more for transportation in order to get within effective range of these activities.

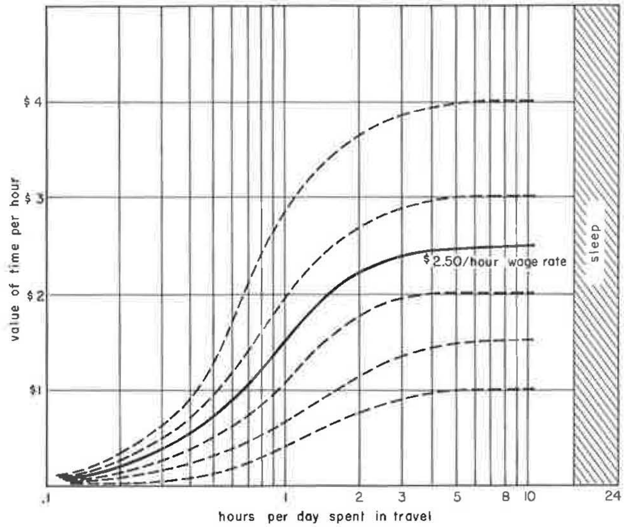


Figure 2. Individual's valuation of time.

## Value of Time

This raises the question of the value of time. A number of studies have been made which set values for the time of automobile users. These studies recognize the difficulty of measuring the value of time because the results are averages—for persons with different incomes traveling for different purposes. Furthermore, most of these studies deal with choices between toll and free facilities on fairly long trips.

The authors suggest that there are two main considerations in an individual's valuation of his personal time. One is his income. The other is the amount of time spent each day in traveling. Because time is a scarce resource for most individuals, it seems reasonable to assume that the more time devoted to a particular activity, such as traveling, the more valuable it becomes. The reason for this is that less time is then available to devote to other activities.

This argument is depicted in Figure 2, which suggests that for small amounts of time (say, 5 min) devoted to travel, time has practically a zero value. However, when time per day devoted to travel exceeds 2 or 3 hr, its value becomes the value of the hourly wage of that individual. In Figure 2 the value used is $2.50, inasmuch as this approximates the mean national wage of production workers. The shape of the curve is purely intuitive.

Similarly, it can be argued that the more income a person commands, the higher the value he will place on his time, and the more he will be willing to pay for savings in traveling. This is suggested in Figure 2 by the family of curves leveling off at different hourly wages.

The preceding paragraphs are obviously not conclusive, only suggestive. Their first purpose has been to suggest that an increasing daily investment of time in travel is viewed as being at increased cost. Their second purpose is to suggest that the higher the person's income, the more highly he will value all time spent in travel. These ideas have a significant impact on the traveller's choice of mode and amount of travel.

## Choice of Mode

Comparison of operating and time costs by mode of travel are extremely difficult and can be deceptive when analyzed on a single-trip, round-trip, or other short-term basis. Proponents of group and individual forms of transportation can produce figures which suggest that either form of transportation is less costly.

However, when costs are treated on a long-term basis, a much sharper and clearer picture of mode choice appears. This picture, furthermore, appears to be completely reasonable in the light of available evidence on mode choice (Table 1).

In Figure 3, the dotted line shows that the cost of purchasing seat-miles of transportation by group transportation is substantially lower over the range up to 15,000 mi per

TABLE 1

MOVEMENT AND TIME COSTS BY MODE

| Miles Traveled | Cost ($) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Individual | | | | | | Group | | | |
| | Base Auto Cost[a] | Movement at $0.03 per Mi[b] | Sub-total | Time at $0.91 per Mi[c] | Total | Per Mile | Movement at $0.057 per Mi[d] | Time[e] | Total | Per Mile |
| 10 | 434 | – | 434 | 1 | 435 | 43.50 | – | 1 | 1 | 0.20 |
| 100 | 434 | 3 | 437 | 9 | 446 | 4.46 | 6 | 14 | 20 | 0.20 |
| 500 | 434 | 15 | 449 | 45 | 494 | 0.98 | 28 | 72 | 100 | 0.20 |
| 1,000 | 434 | 30 | 464 | 91 | 555 | 0.56 | 57 | 143 | 200 | 0.20 |
| 2,000 | 434 | 60 | 494 | 182 | 676 | 0.34 | 114 | 286 | 400 | 0.20 |
| 4,000 | 434 | 120 | 554 | 364 | 918 | 0.23 | 228 | 572 | 800 | 0.20 |
| 6,000 | 434 | 180 | 614 | 546 | 1,160 | 0.19 | 342 | 858 | 1,200 | 0.20 |
| 8,000 | 434 | 240 | 674 | 728 | 1,402 | 0.18 | 456 | 1,140 | 1,600 | 0.20 |
| 10,000 | 434 | 300 | 734 | 910 | 1,644 | 0.16 | 570 | 1,430 | 2,000 | 0.20 |
| 15,000 | 434 | 450 | 884 | 1,360 | 2,244 | 0.15 | 850 | 2,160 | 3,000 | 0.20 |
| 20,000 | 434 | 600 | 1,034 | 1,820 | 2,854 | 0.14 | 1,140 | 2,860 | 4,000 | 0.20 |

[a] Fixed costs divided by 1.5 persons per car.
[b] Variable costs divided by 1.5 persons per car.
[c] Auto journey, speed 11 mph (5); assumed $1.00 per hour value of personal time.
[d] Assumed $0.25 fixed fare divided by mean journey length of 4.4 mi, which is weighted combination of bus and subway-elevated passengers, Chicago area, 1956 (6).
[e] Assumed $1.00 per hour value of personal time; speed is 7 mph; which is weighted combination of bus and subway (elevated journey speeds).

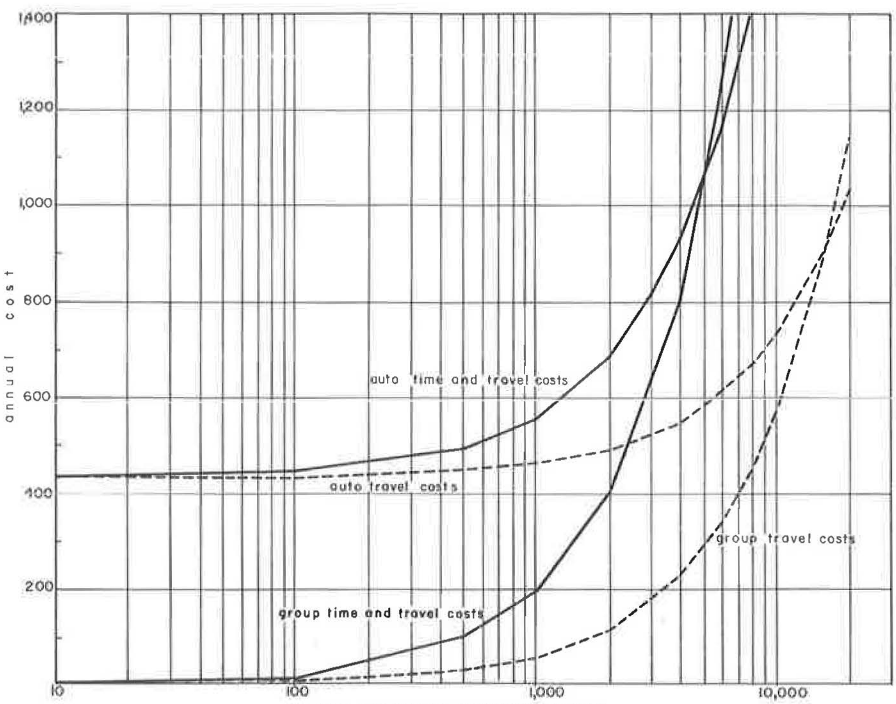


Figure 3. Comparison of annual travel and time costs for individual and group transportation as a function of miles traveled per year.

year. This is because the automobile owner must start from the higher level of fixed investment in a vehicle.

If this is an accurate appraisal (and the figures appear reasonable), then fewer people would use their cars than now do. However, if it is assumed that person time has an average value of $1.00 per hour, then the costs of group transportation use rise to in-

tersect the costs of automobile use at a point where about 6,000 mi of travel per year are undertaken. This is equivalent to a round trip to work and back of 12.5 mi each weekday (five-day week).

Appraising Figure 3, then, one would observe that for those persons who travel less than 6,000 mi per year, group transportation is undoubtedly the less expensive. For those who travel more than 6,000 mi per year, individual transportation is less expensive. Generally, persons with lower incomes live in the older and denser portions of cities; they cannot afford to travel much and their needs are more apt to be met close at hand. Group transportation is much more economical for them. For the suburban family, income and travel distances are greater; individual transportation is a better bargain.

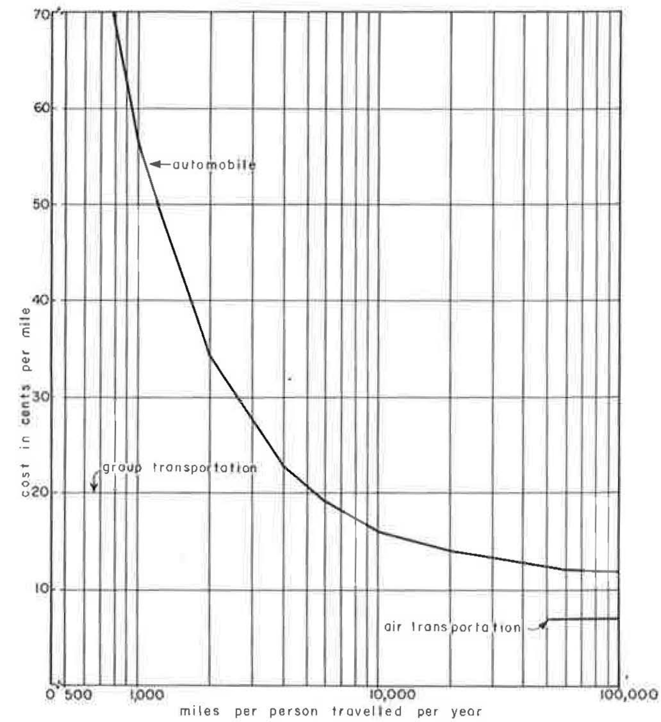


Figure 4. Comparison of time and movement costs per mile and number of miles traveled by mode of travel.

Figure 4 shows the same data as in Figure 3, but on a cost-per-mile instead of on an annual cost basis. This shows clearly how, with increasing use, individual transportation becomes progressively less expensive to the user. The positions of the lines shown here may vary, but the principle remains the same. As an afterthought, the cost of air travel is shown for the persons who travel more than 50,000 mi per year. At \$0.07 per mile and with little time cost (\$1.00 divided by 250 mph is less than a \$0.01 of time per mile) air travel is quite inexpensive when a great deal of traveling must be done.

## Summary

In this part, the choice of transportation mode has been analyzed from the viewpoint of the user, who is assumed to be an economic man with good knowledge of alternative costs.

An analysis of movement costs suggests that the user considers other things besides movement costs in making a choice. If his viewpoint were solely movement costs he would walk for all journeys. Automobile costs would appear to be a high cost form of transportation. Bus travel would be economical for long journeys.

A hypothesis was advanced that time costs (as appraised by the traveler) vary with the amount of travel (in time) per day. This hypothesis is reasonable, but lacking evidence, time costs are considered on a fixed average basis in later parts of this paper.

Using a fixed value of time, choice of mode can be graphed, including both time and movement costs, on an annual basis. This kind of presentation suggests that choice of mode is a function of the amount of travel purchased per year by the consumer. Those who purchase very little travel will tend to use group transportation. Those who purchase more travel will tend to use individual transportation.

## SELECTION OF CAPITAL INVESTMENT POLICY

Selection of a capital investment policy for transportation systems is a critical problem in urban planning, and hence to metropolitan management. The following analysis is focused mainly on the problem of optimizing investment for two modes of transportation—individual and group. Actually, this could be considered as a four-mode problem, because the authors deal with travel on buses, rail rapid transit, arterials, and expressways. However, the investment is only in two modes (rails and expressways).

Much has been written about "balanced" transportation systems. What is or what is not balanced has never been decided and rarely is defined. It might be defined from the viewpoint of metropolitan management as the proportion of persons traveling by individual and group transportation at the point where total transportation costs are least. However, the proportion which is least cost now may very well not be at least cost twenty years from now. Thus the idea of "balance," with its implications of a static situation over time, may be misleading. The problem of the amount and timing of investment is probably more important.

In order to select—or perhaps more properly to move toward—an optimum capital investment policy, a system must be created for determining what is optimum. This system requires both a criterion for selection, and a basis for making the necessary calculations or approximations.

The criterion has already been established: from the viewpoint of metropolitan management, the goal is to minimize the sum of all transportation costs. Hence this part opens with a discussion of systems for calculating optimum points, or, more accurately, for arraying alternative costs.

### Systems for Calculation of Alternative Investment Costs

There seem to be four substantially different methods of calculating alternative investment costs. These include (a) the method of comparing alternative single routes, (b) the method of equal percentage returns, (c) the method of economic evaluation of traffic assignments, and (d) the method of simplified models. These are discussed in turn.

Method of Comparing Alternative Single Routes.—A conventional method of studying alternative costs is to compare the costs of single routes. One route may be compared with another, or with the option of not building it at all. Very detailed accounts have been suggested with this type of work (7, p. 34).

There are two difficulties with this method: (a) the great volume of detailed work, which may be of misleading accuracy, and (b) the fact that a system is not being dealt with (7, p. 95). It is quite possible for a single road or rail line to be unprofitable in itself but to increase profits for a whole system.

Method of Equal Percentage Returns.—Basically, the method of equal percentage returns distributes available investment capital among alternatives on the basis of the marginal rate of return. If two or more activities are independent, the optimum investment policy is one which equates the rate of return on the increments of investment in the several activities.

This holds true as long as there is no, or extremely little, connection between the activities. In simplest form, without budget constraints or an existing physical plant, this is a cumulation of individual maxima for each activity. In a somewhat more realistic framework this approach allocates investment among alternatives subject to budget limitations. For example, if there were no connection between group and individual transportation and an investment in transportation were to be made, the optimum investment would be that split which yielded an equal return on the additional investment in each mode.

There is some evidence for holding that group and individual transportation are independent—at least for crude levels of precision. Keefer (8) has shown that very high percentages (85 percent in Pittsburgh) of transit users are "captives." The other side of the question—how many automobile drivers and passengers are actual "captives" of their mode—has not been answered. Without further evidence of even a crude independence of mode the equal rate of return approach is difficult and dangerous to use for this

problem. The "lumpiness" of efficient investment units between several facilities also makes this approach difficult.

In other areas of metropolitan management concern, where a comprehensive and detailed accounting is impossible, this approach provides a useful yardstick. For example, this is the only feasible way, at present, for evaluating investment policy in transportation against investment policy in land development or hospitals or public open space.

Method of Economic Evaluation of Traffic Assignments.—Traffic assignments currently in use in various transportation studies offer what is probably the most trustworthy means of measuring all costs (that is, all transportation costs) associated with a particular transportation system plan, including both road and transit systems. These methods can estimate the traffic volumes on each link of both road and group transportation systems. Because traffic volumes, coupled with information on road or bus system characteristics, determine time, accident, and vehicle operating costs, it is quite easy to sum up the total costs, including construction costs, for each system plan.

Such a method of accounting, completely computerized, is far superior to the system of comparing alternative single routes. It automatically takes into account the reduced costs which occur when persons use low-cost systems (for example, rail rapid transit or expressways) instead of the higher-cost bus and arterial systems. The increased capital requirements also are taken into account.

One problem with this method—and it may be more theoretical than real—is that because of the time and cost of running computer traffic assignments, not all possible systems may be tested. Hence, there may be one which is superior to all tested solutions. In reality, of course, the severe limitations which restrict the number of possible schemes make it unlikely that a substantially better plan will have been missed.

Method of Simplified Models.—Because the preceding method is long and cumbersome, it is desirable to have another method for two reasons. One is to organize the important constituent determinants of an optimum investment policy so that the principles of optimization are understood. The second is to have a method that can be used in planning—that will permit plans to be prepared which are close to the optimum, so that a smaller range of plans can be tested. More tests on fewer plans presumably would provide greater precision.

Naturally, these models require simplifications and abstractions from the complexities of the real world. There is no harm in this, provided the models are thoroughly understood both in derivation and in purpose.

Several of these models already exist. One is the optimum spacing model, which treats the problem of optimizing investment in expressways in an all-road situation (9, 10). Another model deals with the optimum location of transfer stations in an all-rail problem (11).

Problems which have not been treated include the optimization of subway construction in a sector of varying density, and the problem of the optimization of the mix of road and rail transit improvements. These are examined in the following two sections of this paper.

## A Model for Optimizing Rapid Transit

This section of the paper is an off-shoot from the main argument, in the sense that it is not concerned with both group and individual transportation, but is limited to group transportation. Nevertheless, the problem dealt with here is a complex one of great interest. Its solution should be extremely useful, not only in its present elementary form but also as a base for further refinement and possibly for extension to include both group and automobile transportation.

A question in cities having no form of rail rapid transit is whether to build such a rapid transit line, and if so, how long a line should be built. Assuming that rapid transit should pass through the central business district (CBD), the problem can be stated: how far out should a rapid transit line be built from the CBD? This section presents a mathematical solution to this problem.

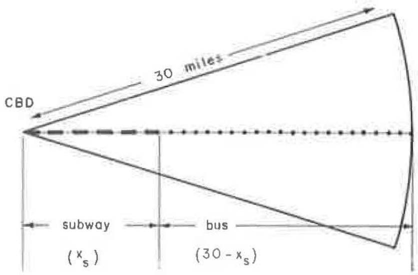


Figure 5.

Assume a sector of the city radiating out from the CBD a maximum distance of 30 mi. This sector is populated with people at a density which declines as distance from the CBD increases. Assume that all these people (or it could be a proportion, either constant or varying) travel to the CBD by bus. Because the angle of the sector is known, this population of bus riders can be considered either as living throughout the sector or as living on a single line—the bus line (see Fig. 5).

Let it be taken, then, that all bus riders live along a bus line, but at a decreasing density from the CBD in accordance with

$$\text{density} = a\, e^{-x/K} \qquad (1)$$

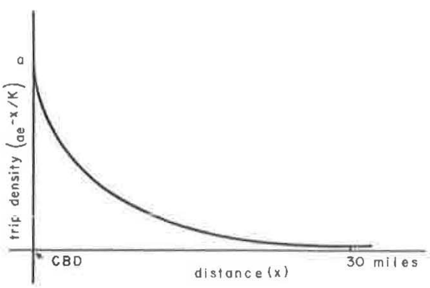


Figure 6.

in which x is distance from the CBD and a and K are constants. This can be graphed as shown in Figure 6.

The problem can now be stated: how far out ($x_s$) should a subway be built from the CBD in order to minimize the sum of travel and construction costs? For simplicity, let it be assumed that all persons travel each day to the CBD by bus, and that wherever they meet the end of the subway line they will transfer, without time loss, to the subway and proceed on the subway. Their reason for transferring is because subway travel is cheaper in time and operating costs than is bus travel. The mathematical statement of this problem follows (12).

For any values of x, say $x_i$ and $x_j$ with $x_i \leq x_j$, $\int_{x_i}^{x_j} a\, e^{-x/K}\, dx$ represents the total number of trips originating within the range $x_i \leq x \leq x_j$, whereas, $\int_{x_i}^{x_j} a\, x\, e^{-x/K}\, dx$ represents the total person-miles of travel resulting from these trips. Now, because all trips with origins in the range $o \leq x \leq x_s$ ($x_s$ is length of subway) use the subway exclusively for a distance of x miles, and all trips with origins in the range $x_s < x \leq 30$ use the subway for $x_s$ miles and use the bus for $(x - x_s)$ miles, the following equation may be developed to sum the costs of travel and subway construction:

$$\text{Total cost} = C_3\, x_s + C_1 \left[ \int_{o}^{x_s} a\, x\, e^{-x/K}\, dx + x_s \int_{x_s}^{30} a\, e^{-x/K} dx \right] +$$

$$C_2 \left[ \int_{x_s}^{30} a\, x\, e^{-x/K}\, dx - x_s \int_{x_s}^{30} a\, e^{-x/K}\, dx \right] \qquad (2)$$

in which $C_3$ is the construction cost of subway travel, in dollars per mile, converted to a daily basis; $C_2$ is bus travel costs, in dollars per mile; and $C_1$ is subway travel costs, in dollars per mile.

In word form, Eq. 2 says that the total costs of transportation in the sector of the city under study are equal to the construction cost of the subway plus the cost of all person-miles of travel on subways plus the cost of all person-miles of travel on buses. To minimize total costs, Eq. 2 is first integrated, then differentiated with respect to $x_s$, equated to zero, and solved for $x_s$. The resulting value of subway length is

$$x_s = -K \ln\left[ e^{-30/K} - \frac{C_3}{(C_1 - C_2)\, a\, K} \right] \quad (3)$$

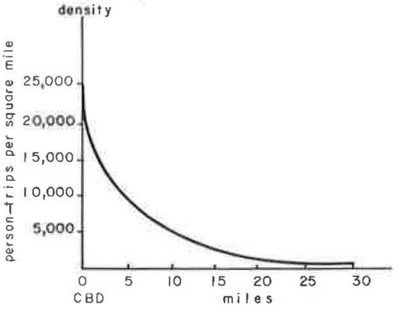


Figure 7.

in which ln is the natural logarithm function.
Now it can be shown that this value of $x_s$ minimizes total cost if, and only if, $C_1 < C_2$. This condition is reasonable because bus travel costs are greater than subway travel costs.

Eq. 3 reveals some interesting and reasonable properties with respect to the unit costs involved, as follows:

1. The length of subway will decrease if construction costs rise.
2. If bus travel costs rise (as by increased operating costs or slower speeds), more miles of subway should be built.
3. If subway costs decrease (as by lowered operating costs or higher speeds), more miles of subway should be built.

Some sample results are now in order. For a = 25,000 person-trips per square mile per day and K = 6, the density relation takes the particular form

$$\text{density} = 25{,}000\, e^{-x/K}, \quad 0 \le x \le 30 \quad (4)$$

which has the form shown in Figure 7 and which is assumed to approximate reality. The rate of decline of the curve can be varied by changing the value of K; this adds to the flexibility of Eq. 3 and, therefore, to its usefulness in finding solutions for different sets of empirical data. Also, assuming $C_1$ = \$0.12 per mile (subway travel, including time cost), $C_2$ = \$0.19 per mile (bus travel, including time cost), and $C_3$ = \$1,500 per mile (subway construction cost per day), Eq. 3 gives $x_s = -6 \ln [e^{-5} - 1{,}500/(-0.07 \times 150{,}000)]$, or $x_s$ = 11.4 mi.

Because the input figures do not pertain to any particular city, the distance value given for $x_s$ in this example should not be considered as being an actual value.

The value of this work is that it provides a simple means for estimating the optimum length of subway construction as a function of trip density, bus travel costs, subway travel costs, and construction costs. The trip density curve, being a declining function, approximates the actual declines in urban densities.

## Optimizing Investment in a Two-Mode Transportation System

In previous sections, ideas have been presented on the goals of travelers and of metropolitan management, and on the choice of transportation from the traveler's viewpoint. Various methods have also been described for estimating optimum investments in transportation systems, including the method of evaluating individual facilities, the method of equal percentage returns, the method of assignments, and the method of simplified models.

In this section, a simplified model is presented which may be used for studying travel and capital costs associated with different investment combinations of improved individual and group transportation facilities. This section attempts to provide a means for answering questions such as: How much should be invested in expressways?; How much

should be invested in rail rapid transit?; and What is the best combination of investments?

An understanding of the relationship between alternative costs should be extremely helpful in planning transportation systems for urban areas. A secondary purpose of this section is to lay the groundwork for computer programs which may consider more complicated situations than here developed. A third purpose is to lay the groundwork for developing a formula for finding the optimum point, or points, for capital investment in group and individual modes of transportation.

In this section, the basic unit dealt with is the person-mile of travel (PMT), which is a small enough unit so that it can be dealt with in continuous terms. The cost of person-miles of travel on different types of facilities is known fairly well. Furthermore, it is possible to estimate reasonably well how PMT will be allocated to different types of facilities as a function of the amount (or spacing) of these facilities. Because the amount (or spacing) of facilities is a direct function of investment, it is thus possible to relate travel costs to investments, and hence to know total costs. Use of the PMT unit avoids the substantial difficulties inherent in dealing with trips as a basic unit.

Throughout this section, the unit of area dealt with is a 1-sq mi section of urban territory, the same assumption used in other "simplified model" solutions described herein. The basic assumption of the unit square mile is that a large urban area of identical density, trip length, transportation facilities, etc., surrounds the square mile under consideration. It is necessary to make this assumption in order to construct the kind of model herein described.

To permit a more rapid presentation of the subject the various variables employed are described as follows:

$G$ = proportion of travel made by group transportation;
$X$ = proportion of individual transportation on expressways;
$R$ = proportion of group transportation on rail rapid transit facilities;
$O_A$, $O_B$, $O_X$, $O_R$ = the respective PMT (operating and time) costs on arterials, buses, expressways, and rail rapid transit, in \$0.01 per mile of person travel;
$C_X$, $C_R$ = construction costs of expressways and rail rapid transit facilities expressed in daily terms;
$T$ = sum of operating costs plus construction costs;
$z_1$, $z_2$, $z_3$ = spacings of expressways, arterials and local streets, respectively;
$\rho$ = trip density, in person-trip destinations per square mile;
$\bar{r}$ = mean trip length;
$y_1$, $y_2$ = spacing of rail rapid transit lines and bus lines, respectively; and
$V_X$, $V_R$ = volumes of persons per day passing points on expressways and rail rapid transit lines, respectively.

Consider plane ABCD in Figure 8. On this plane the horizontal axis represents the percentage, X, of person-miles of travel (PMT) driven on expressways. At point X = 0.0, all person-miles of travel are placed on arterial or local streets. The vertical axis represents O, or the cost of PMT, a joint function of vehicle operating costs (including depreciation) and time costs. The PMT cost declines from $O_A$ to $O_X$ as larger percentages of PMT are placed on expressways, because expressway travel is faster and safer, with less wear and tear occasioned by stop and go driving. The decline is a linear relationship.

Consider also plane EFGH in Figure 9. On this plane the horizontal axis represents the percentage, R, of PMT placed on rapid transit (subway, elevated, and/or monorail, but not express buses). At point R = 0.0, all person-miles of travel are placed on bus systems. The vertical axis represents the cost of PMT, a joint function of fares and time costs. Fares are assumed to cover all operating costs (including vehicle depreciation, labor, fuel, oil, and tire costs) but not to cover any capital costs, whether of roads or of rails, stations, or other capital expenditures.

The PMT cost declines from $O_B$ to $O_R$ as larger percentages of PMT are placed on rail rapid transit. This is primarily because rail rapid transit travel is faster and safer. The decline is a straight-line relationship.

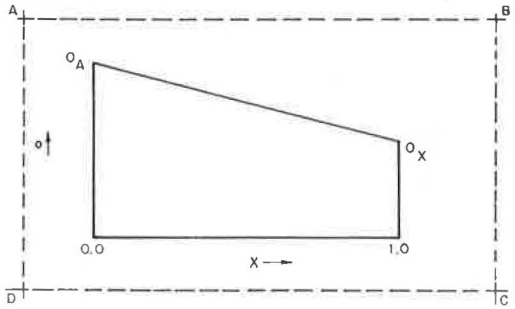


Figure 8.

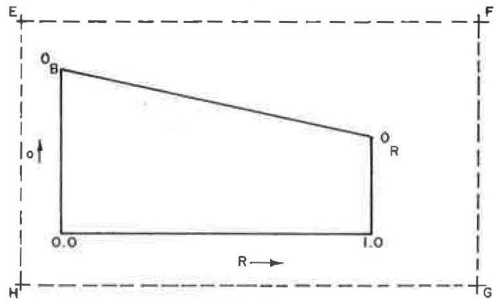


Figure 9.

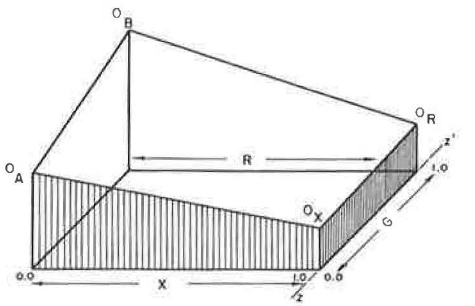


Figure 10. Surface of operating costs (X = R).

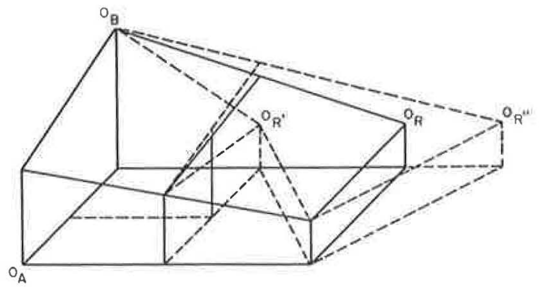


Figure 11. Surface of operating costs (variable R).

In both cases, PMT is expressed as an average cost per mile of travel. This assumption is necessary in dealing with group transportation, because fixed fares produce variable per-mile costs as a function of trip length.

The two planes, ABCD and EFGH, are now placed parallel to each other and at a distance apart on the z axis, which is scaled in units of G; G is 0.0 where intersected by plane ABCD and 1.0 where intersected by plane EFGH. This is shown in Figure 10, from which it is possible to consider the surface of person-miles of travel cost. This surface, identified as $O_BO_RO_XO_A$, gives the person-miles of travel costs for any combination of G and X, but only where X = R.

Inasmuch as the preceding assumption about the equality of R and X is rarely likely to be true, it is necessary to develop a procedure for graphically measuring the costs when R is not equal to X. This is done by simply lengthening or foreshortening the scale on which R is measured so that any value of R can be placed directly opposite any value of X. By this device, as illustrated in Figure 11, the unit costs for any combination of G, X, and R can be calculated.

Obviously, graphical devices are limited in their usefulness for making calculations, although they are very useful in conveying ideas. Hence it is necessary to develop a formula which will express unit costs of transportation for any combination of G, R, and X, as follows:

$$\text{Operating and Time Cost} = \bar{r}\,\rho\, G\,[(1-R)\,O_B + R\,O_R] + \bar{r}\,\rho\,(1-G)\,[(1-X)\,O_A + X\,O_X] \qquad (5)$$

In a city where there are no expressways and no rapid transit lines, all persons would have to travel on arterial streets, either in buses or in individual vehicles. Costs would then be expressed by a simplified version of Eq. 5, as follows:

$$\text{Operating and Time Costs} = \rho\,\bar{r}\,G\,O_B + \rho\,\bar{r}\,(1-G)\,O_A \tag{6}$$

If metropolitan management decides to provide expressway and rail service in the square mile under consideration, some of the residents' PMT will be allocated to the higher type facilities. The proportion, X, of individual PMT allocated to expressways can be calculated from

$$X = \frac{1}{z_1\left[\frac{1}{z_1} + \frac{1}{\bar{r}} + \frac{z_2}{\bar{r}\,(z_1 - z_3)}\right]} \tag{7}$$

which is adapted from Schneider's (13) "direct assignment" formula. Similarly, the proportion, R, or percentage of PMT on rail facilities can be calculated from

$$R = \frac{1}{y_1\left(\frac{1}{y_1} + \frac{1}{\bar{r}}\right)} \tag{8}$$

which is a simplified version of Schneider's formula for a two-mode (bus and rail) system.

However, metropolitan management is conscious of capital investment costs required to permit people to move faster and more safely. These costs are determined by

TABLE 2

TOTAL DAILY COSTS FOR SELECTED PROPORTIONS OF GROUP AND INDIVIDUAL TRANSPORTATION AT VARYING SPACINGS FOR EXPRESSWAYS AND RAIL TRANSIT[1]

(Trip Density = 10,000, Mean Trip Length = 6 Miles)

| Using Group Trans. (%) | Spacing (mi) | | Person-Vol./Mi (1,000's) | | PMT (%) | | Total Daily Costs ($) |
|---|---|---|---|---|---|---|---|
| | Exp. | Rail | Exp. | Rail | Exp. | Rail | |
| 0 | 10 | None | 106 | None | 36 | 0 | 10,206 |
| | 5 | None | 75 | None | 49 | 0 | 9,580 |
| | 3 | None | 54 | None | 59 | 0 | 9,270 |
| | 2 | None | 40 | None | 67 | 0 | 9,560 |
| 25 | 10 | 3 | 80 | 15 | 36 | 67 | 11,002 |
| | 5 | 5 | 56 | 21 | 49 | 56 | 10,720 |
| | 3 | 3 | 40 | 15 | 59 | 67 | 10,510 |
| | 2 | 5 | 30 | 21 | 67 | 56 | 10,800 |
| 50 | 10 | 3 | 53 | 30 | 36 | 67 | 11,382 |
| | 5 | 3 | 38 | 30 | 49 | 67 | 11,270 |
| | 3 | 3 | 27 | 30 | 59 | 67 | 11,360 |
| | 2 | 3 | 20 | 30 | 67 | 67 | 11,650 |
| 75 | 10 | 3 | 26 | 45 | 36 | 67 | 11,692 |
| | 5 | 3 | 19 | 45 | 49 | 67 | 11,780 |
| | 3 | 3 | 14 | 45 | 59 | 67 | 12,030 |
| | 2 | 3 | 10 | 45 | 67 | 67 | 12,400 |
| 100 | None | 10 | None | 112 | 0 | 36 | 13,376 |
| | None | 5 | None | 82 | 0 | 56 | 12,150 |
| | None | 3 | None | 60 | 0 | 67 | 11,690 |
| | None | 2 | None | 45 | 0 | 73 | 11,680 |
| | None | 1 | None | 26 | 0 | 83 | 11,560 |

[1] Rail transit spacings, $Y_1$, of 10, 5, 3, 2, and 1 mi used for each expressway spacing. Only the minimum total cost rail spacings are shown where both group and individual modes of transportation are used.

The following values are assumed in the calculations:

Trip density, $\rho$ = 10,000
Mean trip length, $\bar{r}$ = 6 mi
Arterial autos, $O_A$ = $0.20/mi
Expressway autos $O_X$ = $0.10/mi
Rail transit, $O_R$ = $0.15/mi
Buses, $O_B$ = $0.26/mi
Arterial spacing, $z_2$ = 1 mi
Local street spacing, $z_3$ = 0.1 mi
Expressway spacing, $z_1$ = as indicated
Capital costs at 8% interest, 25 years for recovery. Expressways are $1,460 per day or $5 million per mile. Rail at $880 per day or $3 million per mile.

$$\text{Expressway investment} = \frac{2\,C_X}{z_1} \tag{9}$$

$$\text{Rail rapid transit investment} = \frac{2\,C_R}{Y_1} \tag{10}$$

$$\text{Total investment} = 2\left(\frac{C_X}{z_1} + \frac{C_R}{Y_1}\right) \tag{11}$$

Two examples have been studied. In the first, a medium density area is investigated—one which has a trip population of 10,000 trips per square mile, equivalent to about 5,000 persons per square mile (Table 2). This is a solidly built-up suburban settlement. The ratio of bus:rapid transit:arterial auto:expressway auto costs was taken as 26:15:20:10. This means that the individual travel costs were lower than group costs by about one-third, whereas express travel costs (either expressway or rail rapid transit) were considered about one-half of those on unimproved facilities. These are conservative estimates. Again, the figures given here are subordinate to the principles and methods.

TABLE 3

TOTAL DAILY COSTS FOR SELECTED PROPORTIONS OF GROUP AND INDIVIDUAL TRANSPORTATION AT VARYING SPACINGS FOR EXPRESSWAYS AND RAIL TRANSIT[1]

(Trip Density = 50,000, Mean Trip Length = 6 Miles)

| Using Group Trans. (%) | Spacing (mi) | | Person-Vol./Mi (1,000's) | | PMT (%) | | Total Daily Costs ($) |
|---|---|---|---|---|---|---|---|
| | Exp. | Rail | Exp. | Rail | Exp. | Rail | |
| 0 | 10 | None | 545 | None | 36 | 0 | 67,171 |
| | 5 | None | 391 | None | 52 | 0 | 60,542 |
| | 3 | None | 284 | None | 63 | 0 | 56,705 |
| | 2 | None | 211 | None | 70 | 0 | 55,055 |
| | 1 | None | 119 | None | 79 | 0 | 56,410 |
| 25 | 10 | 3 | 409 | 75 | 36 | 67 | 66,649 |
| | 5 | 3 | 293 | 75 | 52 | 67 | 61,970 |
| | 3 | 3 | 213 | 75 | 63 | 67 | 59,483 |
| | 2 | 3 | 158 | 75 | 70 | 67 | 58,733 |
| | 1 | 3 | 89 | 75 | 79 | 67 | 61,213 |
| 50 | 10 | 2 | 273 | 112 | 36 | 75 | 63,799 |
| | 5 | 2 | 195 | 112 | 52 | 75 | 61,070 |
| | 3 | 2 | 142 | 112 | 63 | 75 | 59,993 |
| | 2 | 2 | 106 | 112 | 70 | 75 | 60,083 |
| | 1 | 2 | 60 | 112 | 79 | 75 | 63,688 |
| 75 | 10 | 1 | 136 | 96 | 36 | 86 | 60,607 |
| | 5 | 2 | 98 | 169 | 52 | 75 | 59,870 |
| | 3 | 2 | 71 | 169 | 63 | 75 | 60,083 |
| | 2 | 2 | 53 | 169 | 70 | 75 | 61,133 |
| | 1 | 2 | 30 | 169 | 79 | 75 | 65,863 |
| 100 | None | 10 | None | 562 | 0 | 38 | 66,286 |
| | None | 5 | None | 409 | 0 | 54 | 61,171 |
| | None | 3 | None | 300 | 0 | 67 | 58,053 |
| | None | 2 | None | 225 | 0 | 75 | 56,328 |
| | None | 1 | None | 129 | 0 | 86 | 55,656 |

[1] Rail transit spacings, $Y_1$, of 10, 5, 3, 2, and 1 mi used for each expressway spacing. Only the minimum total cost rail spacings are shown where both group and individual modes of transportation are used.

The following values are assumed in the calculations:

Trip density, $\rho$ = 50,000
Mean trip length, $\bar{r}$ = 6 mi
Arterial autos, $O_A$ = \$0.28/mi
Expressway autos, $O_X$ = \$0.115/mi
Rail transit, $O_R$ = \$0.15/mi
Buses, $O_B$ = \$0.26/mi
Arterial spacing, $z_2$ = 0.5 mi
Local street spacing, $z_3$ = 0.1 mi
Expressway spacing, $z_1$ = as indicated
Capital costs at 8% interest, 25 years for recovery. Expressways are \$5,855 per day or \$20 million per mile. Rail at \$2,928 per day or \$10 million per mile.

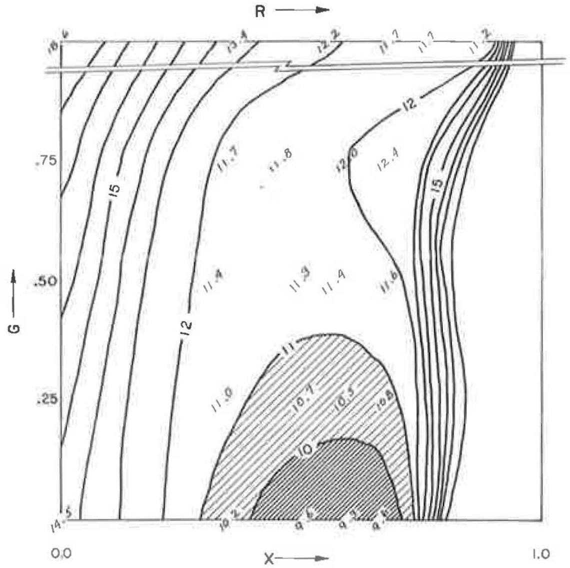


Figure 12. Cost surface for Example 1. (Data plots where G < 0.75 are with respect to X.)

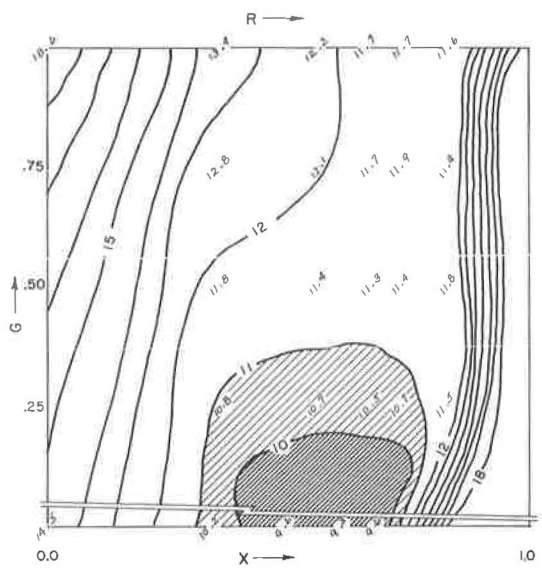


Figure 13. Cost surface for Example 1. (Data plots where G ≥ 0.25 are with respect to R.)

In Figures 12 and 13 the resulting costs surfaces are shown by the use of the isoline or contour technique. A word is necessary on the construction of these figures. Inasmuch as four variables are being presented (T, G, R, and X) it is obvious that one variable cannot be shown, except in the case where one of the other variables is zero. In Figure 12, the missing variable is R, which is not shown except along the line G = 1.0. Therefore, in each plot, for any particular value of G and X, the minimum T value is plotted as determined by one or another of the values of R. The mate of Figure 12 is Figure 13, in which the X values disappear, except along the X-axis.

Both Figures 12 and 13 show that the minimum cost point is associated with optimum investment in expressways. Investment in rail rapid transit facilities would produce some gains, but not nearly as fast as investment in expressways. There is a lightly-defined minimum point in the all group world, but it is substantially more costly than the minimum point in the all individual transportation solution.

In contrast, a very high density area was selected as the second example. A trip density of 50,000 person-trips per day per square mile was chosen, equivalent to about 25,000 persons per square mile (Table 3). In this example, the ratio of bus:rapid transit:arterial auto:expressway travel costs was taken as 26:15:28:11½. This means that automobile travel on arterial streets was set higher than bus costs. This is conceivable if congestion and parking fees are high enough.

The result, as shown in Figures 14 and 15, is to produce a definite, two-minimum solution. Either an all expressway or an all group transportation solution would produce minimum costs of about $55,000 per day per square mile. However, it must be remembered that the costs of constructing facilities were not forced up as a function of increased volume usage. Probably the costs of expressways would rise faster than those of rail rapid transit facilities at this density; the inclusion of these costs might show a clear minimum in the group transportation world.

With such cost surfaces placed in front of metropolitan management, the direction and timing of investment can be studied with much greater facility than otherwise. For most cities, with medium to low densities, and with G values of about 0.25 or less, the direction of investment will probably be toward the expressway solution. For high-density cities, where G > 0.5 it may be more desirable to move toward the all-transit solution. Compromising by trying to maintain a dual policy is probably the most expensive policy.

Density plays an extremely important part in determining costs —not directly, because the quantity $\rho$ does not appear in the equations fixing the proportionate usage on expressway or rail lines, but indirectly in determining costs of construction and speed of travel.

These observations appear reasonable, but must be treated with some caution. One of the reasons for caution is that the foregoing calculations have not varied costs of construction, costs of travel, or speeds as functions of the volumes of persons using each type of facility. Such changes might change the cost surfaces. Second, the model is based on the necessary assumption of a unit square mile. This assumption has obvious limitations. Third, the assumption of a gridded rail transit network is weak; different formulas governing allocation of group PMT to rail rapid transit should perhaps be developed.

Nevertheless, these known difficulties do not detract from the basically simple method of cost surfaces which has been presented here. It will be seen that this method can readily be extended and made more "realistic" by programing it for a computer. The calculations necessary to produce Tables 2 and 3 took about two man-days; a computer could produce more complete answers in minutes. A computer program could take into account:

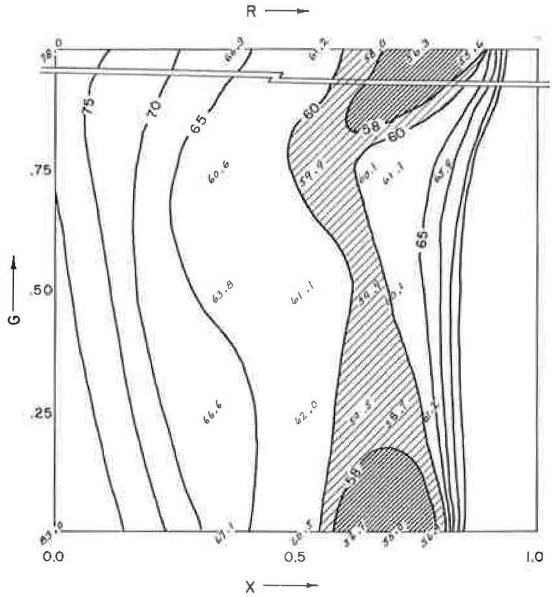


Figure 14. Cost surface for Example 2. (Data plots where G < 0.75 are with respect to X.)

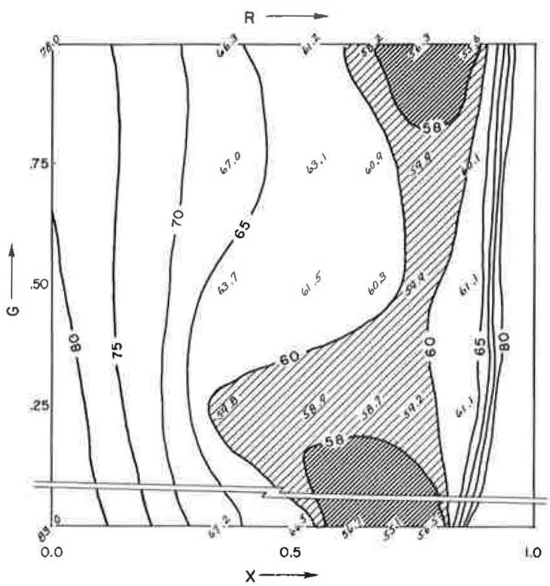


Figure 15. Cost surface for Example 2. (Data plots where G ≥ 0.25 are with respect to R.)

1. Travel costs (time, accidents, and operating costs) as direct functions of volumes on each type.

2. Different capital costs as a function of volumes on each type of road or group transit facility.
3. Capital costs as functions of population density.
4. Variable fares.
5. Increased capital costs of rapid transit facilities if fares do not cover operating costs; reduced capital costs if fares more than cover operating costs.

## SUMMARY AND CONCLUSIONS

This paper was triggered by the question of congestion tolls, but has been focused on the problem of investment in transportation systems of various types. There are two main reasons for this change in focus. First, congestion toll accounting does not take the supply of facilities into account; it is static in outlook, hence is an inadequate framework for planning. Second, it does not deal with the questions of mode of travel or of toll roads where tolls were imposed for reasons of financing.

An attempt has been made to provide a framework for making investment decisions across the board for both individual and group modes of transporting people within urban areas. The viewpoint taken is that of metropolitan management, a hypothetical person or group concerned with urban affairs.

To make investment decisions, metropolitan management must establish an accounting system and it must understand how people will behave when given certain choices. The proposed accounting system includes people's travel costs by mode, and metropolitan management's costs in supplying new transportation facilities. The rule is that the accounting system shall be as inclusive as possible. The goals of site users and non-transportation goals of metropolitan management are examined; but present knowledge, lack of theory, and data limitations prevent their inclusion within the accounting framework. Hence metropolitan management accounts, basically, for personal time, accident costs, vehicle operating costs, and capital (construction and right-of-way) costs in deciding how it should best invest in transportation.

The behavior of people was studied briefly. It is assumed that people are selfish in their choice of mode and that their personal time is of real value to them because its supply is fixed. Choice of mode is clearly not made with respect to movement costs alone; time does have value. A long-term view of alternative transportation costs suggests that the amount of travel consumed annually is important in determining mode of travel. When less than 6,000 to 7,000 miles of travel are undertaken per person each year, group transportation is less expensive. When more than 6,000 to 7,000 miles are traveled, individual travel is less expensive.

To set up a decision framework, all costs were cast in terms of person-miles of travel. Such a unit is needed to make valid cross-comparisons between modes. A model was developed based on a unit square mile of urban terrain.

First, cost surfaces were developed for travel costs (time, accident, and operating costs) as functions of the proportions of PMT allocated to group transportation, G, and to expressways, X, and rail rapid transit, R. The rules for the allocation of automobile PMT to expressways, X, and for the allocation of bus PMT to rail rapid transit, R, were fixed by formula, as functions of expressway and rail rapid transit spacing. The formula assumes that people will allocate PMT to higher-speed facilities if they are present. No formula for allocation of PMT to the group or non-group modes, G, was used; instead, costs associated with many values of, G, were studied.

Second, capital costs were calculated for various values of G, R, and X, and a total cost surface was created. Two examples show how these surfaces appear in medium- and high-density situations.

Given these surfaces, some tentative answers can be provided to three questions raised earlier: (1) What total investment should be made in transportation facilities? (2) What types of facilities should be invested in and how much of each? (3) What role should subsidy or tolls play in the transportation system? There are two further questions of equal importance which are not directly answered here: (4) What should be the timing of investment? (5) Where in the region should the investment be made?

## What Total Investment Should Be Made in Transportation Facilities?

Ideally, investment in transportation should be made up to the point where the return on transportation investment is equal to the return on all other metropolitan investments. This would achieve metropolitan management's goal of optimum allocation of resources. But this requires cross-comparisons of such different community investments as transportation and public health, and there is not yet capability for fully evaluating or equating the consequences of different investments in these areas.

Instead, one must be content with guaranteeing achievement of a prior and less inclusive goal—to minimize total transportation costs. The inclusion of an adequate interest rate (7 to 10 percent) within the minimization cost framework is desirable. Having this kind of return on investment provides assurance against over-investing in the transportation sector.

The answer to the first question, then, is that in the absence of criteria and procedures to determine and compare the relative community benefit from investment in alternate sectors of the public economy, the transportation investment goal is to move toward a minimization of total transportation costs—both travel and investment costs.

## What Types of Transportation Facilities Should Be Invested in and How Much of Each?

There are really two questions involved in this section. These are: (1) What is the modal split likely to be? and (2) What express facilities should be built for each mode—that is, individual and group transportation? These are difficult questions, but answering them is facilitated by reference to the diagrams of transportation cost surfaces shown in Figures 8-15.

Modal Split.—First, choice of mode appears to be a function of the amount of transportation being purchased by the consumer and of the relative cost to him of alternative modes. Many people purchase so little transportation that mass transportation is always more economical, as shown in Figure 3. Others, by reason of age or disability, cannot drive. But for most people, enough transportation is purchased so that they become discriminating. For these people, relative transportation costs affect their allocation of their PMT to one or another system.

Relative costs are composed of movement costs (fares, vehicle operation, accidents, depreciation, etc.) and time costs. Relative cost between individual and group modes of travel may vary substantially on a per-mile basis. In medium- to low-density areas, individual modes of transportation generally are cheaper—that is, the plane of travel costs is tilted down toward the individual transportation. However, in very high-density areas, the group modes may be substantially equal to or even lower in cost than the individual transportation modes.

Those who purchase enough transportation to be discriminating will probably select mode on the basis of relative cost. How these persons will apportion their PMT, on the average, between group and individual transportation is not known. (Probably formulas will be developed shortly which will make the estimation of mode choice easier, just as Schneider's direct assignment formula (13) makes possible the estimation of allocation of PMT between arterials and expressways.) One can, however, study the relative costs, as was done herein, then assume that, over time, people will generally move toward the lower cost portion of the surface. In any event, it is possible to array the costs as a function of all values of G. Knowing the present value of G, it is possible to estimate what changes will be made and in what direction to invest.

What Express Facilities Should Be Built for Each Mode?—The amount of express facilities which should be built for each mode can be calculated separately for each mode. This is simply the optimum spacing problem. A special solution for rail rapid transit, not using the unit square mile approach, was also given herein.

The question of the proper combination of investments is more difficult, but some things can be inferred from a study of the surfaces presented in this paper. The inferences must be treated with caution because of the limited number of examples studied and for the other reasons cited previously.

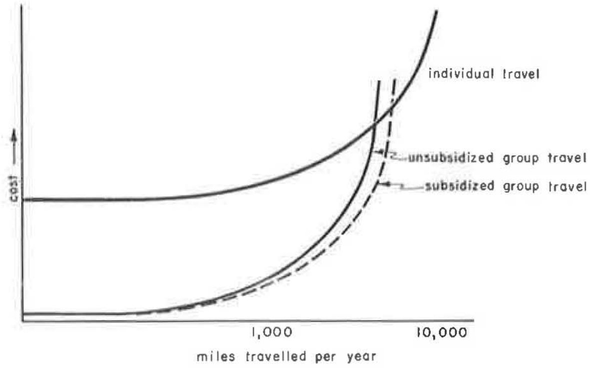


Figure 16.

(a) Initial investment in rail facilities, expressways, or any combination of these facilities will almost always produce some gain. The reason for this is that investment cost, when placed on a daily basis, is a small proportion (10 to 20 percent) of total daily travel costs, yet it will cause substantial reductions in daily travel costs.

(b) Exclusive investment in expressway or rail rapid transit would appear to produce greater gains than a combination of these two types.

(c) Combination investments generally appear to be more expensive because the capital requirements are high and full utilization of each type can not be expected.

(d) The direction in which investments should be made can be seen by determining where on the surface of total cost a particular area is at present. If the proportion of mode split of PMT is less than 0.5, the more economical investment pattern would probably be toward expressways, where the ultimate minimum costs will probably be least. If the proportion of PMT on group modes is greater than 0.5, serious consideration should be given to an all-rail investment pattern.

What Role Should Subsidy or Tolls Play?

Subsidies and tolls are basically means of affecting choice of mode or route of travel. They are actually points along a continuum of encouragement, neutrality, and discouragement. The authors consider subsidies and tolls only from this viewpoint, and not from the unnecessarily strict viewpoint of requiring a tax or payment for every increment of benefit which is conferred on people. A great deal of confusion arises from too strict an interpretation of use taxation. It would be ridiculous, for example, to require all liquor taxes to be devoted to curing alcoholics.

As control devices, either subsidies or tolls are weak because they affect only a minority of travel costs—that is, the movement portion of the costs. The larger proportion—time costs—is therefore still decisive. Inasmuch as tolls take effect as a function of a person's value of time, and time value probably is mainly a function of income, tolls are highly discriminatory, income-wise. The most effective encouragement or discouragement is not subsidy or toll, but relative changes in speed and safety.

Subsidies are generally discussed only in the group transportation world. The effect of subsidies, illustrated by Figure 16, is simply to reduce the apparent cost to the user, and thus to increase the amount of annual travel within which group transportation is considered less costly. Whether this is worth it or not is not known; much would depend on density and on income level. Furthermore, the effect of a subsidy may not be great, because, as already mentioned, it only affects the movement portion of the costs.

Tolls can be considered in two groups. In one group are the tolls imposed on roads as devices for providing financing when other financial means are not available. Major tollways conceived prior to the 1956 Highway Act fall in this category. These facilities provide service to those who wish to select it far ahead of the time when such roads would otherwise be built. Lives are saved which otherwise would have been lost, and those who use these roads confer benefits not only on themselves but also on those who do not use them. However, tollways within urban areas do create definite problems which would not exist if they were free roads.

Congestion tolls form the second type of tolls. These can be considered in two classes: congestion tolls on express facilities and congestion tolls applied, blanket-

fashion, to congested arterials. In each case, the proponents of these tolls have presumed that by reducing congestion on one road or in one area they are conferring benefits to society. These benefits are at best problematical, and may be negative. As Haikalis (16) has shown, travel on a congested expressway may be substantially less costly than travel on an uncongested arterial. Thus, forcing people by tolls off expressways may well increase total social costs.

Congestion tolls applied to arterials (which are generally congested throughout an entire area) would undoubtedly force some drivers off arterials onto still higher-cost local streets, or prevent them from coming to an area such as the central business district. It would be difficult to account for the complete social costs resulting from such a policy, but one could be sure of the unpopularity of such a measure.

Clearly, no hard and fast conclusions can be drawn in this paper on tolls and subsidies except to say that they affect only a small proportion of travel costs and are, hence, weak devices for controlling the flow of traffic.

The main point which the authors wish to make is that through the use of a model for constructing cost surfaces, such as has been suggested here, the alternative costs arising out of different investment policies can be studied quite easily. Such cost pictures, and the improved versions which will come in time, should be of substantial benefit to metropolitan management in the future.

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# The Basic Theory of Efficiency Tolls

## *The Tolled, the Tolled-Off, and the Un-Tolled*

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•TRAFFIC CONGESTION is attracting the increasing attention of economists of theoretical and mathematical bent, especially those of the welfare school. Some among them have the temerity to suggest that the application of economic analysis to the congestion problem, followed by the use of sophisticated pricing techniques, could contribute to the solution of the congestion problem, increase highway efficiency, and promote the public welfare. Requiring, as it does, a large departure from both "traditional" reasoning and current practice, the idea has not been well received nor even understood in much of the noneconomic world. It is popularly regarded as an effort to discourage highway travel by pricing it out of the market by high tolls or prices.

This paper endeavors within small compass to explain the basic ideas dispassionately and to show that the underlying concepts are neither frivolous nor diabolical. In fact, an understanding of the reasoning behind them may contribute to everyone's understanding of traffic phenomena. At the same time, the paper raises certain questions which seem not to have been fully thought through, and which suggest that one might well have reservations about efficiency pricing, not only on broad social or political grounds, but also within the confines of rigorous economic analysis.

### THE TOLLSTERS

Traffic congestion can, of course, be found on any highway facility and at any hour of the day. In the usual circumstance and in its more extreme form, however, congestion is a temporal affair occasioned by uneven traffic flows which reflect the rhythms in patterns of living. One form of peaking takes place on weekends and over holidays as people endeavor to satisfy their desires for recreation and social activity. Because of its very nature, perhaps because this sort of travel is regarded as part of leisure activity itself, this kind of congestion seems rather more acceptable than the second kind.

Congestion in the daily movement to and from work in urban areas is attracting much attention. It is directly related to the grim business of making a living. It takes place regularly—on the order of twice a day, 250 days per year. It is generally regarded as irksome. With increasing urbanization, it becomes ever more difficult and costly to do something about it by engineering works.

#### Traffic Flow

The man in the street is well aware that traffic congestion reduces the quality of highway travel, most obviously through reductions in speed. But it will be useful to state this formally. At low volumes, the average speed of traffic is independent of the flow rate and is determined by geometric design and speed laws. With increases in traffic flow, a point is reached where the average speed begins to drop slightly. As flow builds up, speed drops more rapidly. Also, the possibility of a breakdown (the result of stall or accident) in the smooth flow increases, causing both speed and traffic volume to fall. Without a breakdown, however, traffic builds up to a maximum level

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as speed decreases. The maximum is reached when the effect of increasing vehicle density on the road is no longer sufficient to offset the effect of a speed reduction. It will be seen that maximum traffic flow can only be brought about through reductions in speed—that is to say, increases in travel time. As a matter of convenient exposition, the emphasis in this paper is on time costs and savings; but it should be recognized that congestion may increase other user costs (operations and accidents, for example) and that reduction of such costs through highway improvements are properly regarded as highway benefits.

## The Engineer's Approach to Congestion

The underlying rationale of toll rationing is not as foreign to the thinking of highway and traffic engineers as is often supposed. They are eternally concerned with capacity and efficiency problems. For example, highway designers deliberately fail to provide for free-flowing traffic under all anticipated traffic conditions. In the typical rural situation, they endeavor to design for the anticipated 30th-highest hourly volume of traffic during the design year, "because to design for the highest single-hour volume of traffic to be expected during an entire year would be wasteful" (1). In an urban situation, "the average of the 52 weekly peak hours is a suitable traffic volume for design. In a broad sense, this volume is close to the 26th-highest volume" (1). What this means is that maximum hourly volumes are expected to be greater than design hourly volumes, but this traffic can be carried at reduced levels of comfort and convenience to drivers, and, of course, with losses in time. One example shows a median speed of 32 mph on urban freeways at "possible" capacity, and 50 percent greater speed (48 mph) under "freely flowing" traffic conditions.

The design speeds developed by highway engineers intentionally provide delays to some highway users. They are "predicated upon acceptability to nearly all drivers; this is in recognition of the fact that it would be unwise economically to make provision for the foolhardy actions of irresponsibly fast drivers" (1).

Still another seemingly intuitive economic judgment is exercised. Design speeds are established at higher levels for rural freeways than for urban, and at higher levels for urban areas of moderate development than for such areas of concentrated development.

In the design and spacing of freeway interchanges efforts may be made to keep some traffic off freeways so that traffic on the freeways will have less congestion (smoother flow). In this connection, priority seems to be given to the longer-distance traffic, presumably because larger chunks of usable time will be saved to individual users.

Traffic engineers constantly work to increase the efficiency of operations on existing highway facilities. Traffic control systems are designed to improve traffic flows, often by increasing waiting times of some users in order to reduce waiting times of a larger number of users. A more drastic measure, practiced in a few instances and under serious discussion in many more, is the closing of selected freeway ramps at certain times in order to increase the efficiency of flows on the freeway system. There is also talk of rationing highway space by decree; for example, the prohibition of trucks on congested highway facilities during peak periods.

The foregoing engineering techniques are usually regarded either as "practical" economics or temporary expedients. The ultimate goal of engineers is to expand highway capacity to provide free-flowing traffic at "desired" speeds of most of the drivers during most of the year. Much of the economic justification for the expansion, however, is based on the finding that travel times will be reduced. These reductions in travel times, converted into money equivalents, are regarded as highway benefits to be set off against highway costs. This is but another way of saying that current congestion conditions occasion costs to highway users.

## The Economist's Approach to Congestion

The "traditional" approach of the economist is not unlike that of the engineer. Although he might insist upon a more rigorous finding of benefit and a more exact accounting of costs than is found in many highway analyses, he would sanction highway expan-

sion as long as highway benefits exceed highway costs. If benefits are not sufficient to justify added costs, he might conclude that letting congestion develop is a better choice. But where congestion will exist either as a short-run, a long-run, or an inescapable condition, a third policy alternative may deserve consideration: to take positive measures to control the volume of road users in order to mitigate congestion.

The economic question concerning the wisdom of this course can be phrased in the same way as for highway expansion: Would the benefits of traffic restriction be greater than the costs created? The benefits at issue are similar to those occurring from highway expansion: by reducing traffic flow, "savings" in travel time, accidents, operating costs, etc., are provided for those who continue to use the highway. The traffic flow curve mentioned previously indicated that after a certain point, as flow increases, speeds are reduced and travel times increase. Each vehicle added to a road during a given time period increases the total travel time for all users, not merely by the amount of time of the added user, but by a fractional addition to the travel times of all other users. Thus, in terms familiar to the economist, congestion creates costs. As traffic flow rises, average travel times increase; the marginal time increment is greater than the actual time experienced by the marginal user. Take away the marginal user, and the average time for each of the remaining users is reduced. The saving of congestion costs is, of course, exactly the same as the "benefit" of reduced travel time due to highway expansion, with this exception: if traffic is restricted, instead of road capacity added, fewer users enjoy the benefits.

However, the costs to be compared with the benefits are altogether different. Instead of prices of land and other resources needed to provide highways, the cost arising from traffic restriction is the loss to users who must be prevented or induced not to use a congested road. The amount of the loss depends on what alternatives are available to those who are diverted.

Some motorists might be simply diverted to other highway routes. Others could choose to use public transportation, to share rides with other motorists, to select different trip destinations, or simply to travel less. Some might be persuaded to change their times of travel to uncongested hours of the day. Downtown shoppers could be induced to avoid the afternoon rush hour, if traffic congestion has not already discouraged them. The more difficult goal, but at the same time the more meaningful, would be to stimulate a staggering of working hours. On a more drastic scale there might be substantial changes in ways of life: homeowners might change their residences, employed persons their jobs, employers the places of employment.

In any case, the purpose of restricting traffic would be to produce a net gain—an excess of benefits over losses. On a congested road, the object would be to provide improved highway service for some of the users, at the cost of denying the road's service altogether for the remainder. The merits of this policy might be weighed against the net gain, if any, from enlarging the road system, or against the virtues of doing nothing. The alternative which produced the greatest return (or the least loss) would be favored.

Of course, the comparison of costs with the benefits of traffic restriction is far more difficult than in the case of analyzing road improvement projects. In either instance, the benefits of service improvement can be cautiously estimated. But on the cost side, traffic restriction offers no solid measure such as the actual costs of right-of-way acquisition and highway construction. The losses incident to diverting traffic can take the many forms previously mentioned. If vehicles were only diverted to other highways, then savings in time, accidents, and operating costs on a decongested road might be set off directly against increases in these same factors for motorists who were induced to use less satisfactory routes. But how would the cost of car pooling, use of public transit, travel to different destinations, or not traveling at all, be balanced against the gains from decongestion?

## The Toll Proposal

Economists, long familiar with the idea of equating marginal cost and price, have suggested pricing as the appropriate way of restricting traffic. A toll charge upon a congested road, which tested the value of the service to users by their willingness to

pay, would sort out the motorists which had the least to lose by being removed. The toll would be set equal to what was believed to be the value of the marginal benefit produced by removing a user. Any motorist who thought his loss from being diverted would be greater than the size of the toll would pay the price. Thus, the loss to any motorist who refused to pay could be considered less than the size of the gain due to his absence. To complete its virtues, the toll method would do the job of restriction by voluntary action on the part of motorists.

The novel contribution of this proposal is that the prices, which are sometimes called "efficiency tolls," would be unrelated to the actual cost of highways. The revenue earned by the tolls would be no more than an incidental by-product of the pricing program. This itself would be a substantial departure from familiar highway tax policy, but some economists have argued that modern circumstances compel a revision of pricing objectives. Instead of earning revenue to build more roads, the primary purpose of pricing should be, it is argued, to achieve optimum utilization of the existing highway system, by controlling and directing the volume of use. For example, Vickrey (2) sees the need to avoid "wasteful expenditure on excessively extensive facilities." Buchanan (3) contends that "the reduction of congestion by road expansion can never represent an adequate solution in major urban centers." It appears, he says, that "with relatively little change or modification the system of highway user taxation now employed could be made to approach one which would achieve efficient operation of the existing highway structure."

## Basic Theory of Efficiency Tolls

On first impression, it seems quite unreasonable to collect tolls that are unrelated to actual highway costs. However, the initial capital costs of any existing highway, for which use is to be manipulated by tolls, are regarded as sunk; in this sense, the highway is costless. The use of any toll revenue that may be forthcoming is irrelevant to the pure theory, except that it cannot be given back directly to those who pay it or no rationing would take place. Perhaps what bothers many people most about the efficiency toll proposal, in its pure form, is this apparently pointless production of revenues unneeded to meet expenses.

However, economists invoke a theory of "social cost" to justify rationing charges. Instead of normal highway expenses, they look to the costs of congestion which users inflict upon each other as a cost basis for the prices. They argue that when optimum utilization of highways is the pricing objective, congestion costs should be compensated with user charges; just as actual highway costs should be defrayed by user taxes when expanding the road system is the objective. A motorist, it is said, should be made aware of all costs involved in his decision to drive. The individual motorist is aware only of his own travel time on a congested highway, not the increased time that his presence causes others. If a money value is given to the time of road users, it may be said that a motorist inflicts "social costs" upon other motorists by reason of his presence.

No motorist should decide to use a road, the theory continues, unless the value of his trip suffices to cover both the "private" and "social" costs associated with his use. Therefore, a toll charge which reflects social cost to him provides a fair test of how badly he really wants to travel.

The current vogue of this theory is apparent to any transportation student. Analysts have claimed that automobile users are not paying the full cost of their highway use; and that this fact especially distorts the urban transport scene in favor of the automobile. It is argued that costs per user go up rather than down with growing utilization of highways. It is even suggested that the failure to price the social costs of congestion amounts to an outright subsidy to motorists.

It has been observed, in connection with the toll proposal, that the price would be set according to some estimate of marginal benefit. Is this pricing basis the same as the one which asserts that highway users are obliged to pay for social costs? On the surface, the concepts seem to be the same. In terms of social cost, marginal benefit refers to the congestion cost eliminated by removing one vehicle; marginal social cost refers to the congestion cost occasioned by adding a vehicle. At any given volume of

traffic, marginal benefit and marginal social cost are equal, because one is simply the reverse of the other. Thus, setting a price to cover marginal social cost would appear to be the same as making it equal to marginal benefit.

But it should be noted that a price imposed to produce a benefit by means of restriction is not identical to a price charged to cover a cost as an obligation. The difference is subtle but important. Marginal social cost indicates what the benefit would be to users of a congested highway if one of their number were removed. But that benefit will not necessarily result from setting a toll charge equal to marginal social cost. Suppose that all users were willing to pay such a toll. No benefit would result. Or suppose that on a highly congested highway a very large toll brought but a very small response. In this case, motorists would be asked to pay a large price in return for a small benefit.

Those who accept the social cost theory must begin with an assumption that only a congestion-free highway should be toll-free, and that any degree of traffic congestion on highways gives sufficient justification for charging restrictive prices. Beesley and Roth (4), for example, find that there is reason to restrain the use of highways if two conditions are found: (1) that "use of space by one unit of traffic affects the terms on which other units can use it (which is their way of defining "congestion"), and (2) "when each road user makes his own separate decision when and to what extent to use roads," (which is the typical behavior of an automobile driver). If, then, a toll charge set to equal marginal benefit is very much larger than the average benefit produced to each user who pays it—if indeed any benefit is produced—should there be any complaints? It might be concluded that the toll should have been charged anyhow, in order to pay for social costs. But what would be the attitude of the tolled? Does one know that these users, as individuals, are actually better off than they were before the toll? Would they rather have suffered the congestion (and time losses), and saved the toll, which represents hard purchasing power extracted from their pockets? The fact that they are willing to pay the toll gives no answer. Although it is obvious that they prefer the tolled facility to any alternative, it can scarcely be asserted that they willingly pay because of the benefits of time saving they are supposed to enjoy.

The "Costless" Transfer.—Fortunately for the economists at this point, they have a coup de grace to administer. Let none of the tolled harbor the thought that he might be better off with a little more congestion and no toll to pay. Leaving aside the toll collection process itself (for purposes of discussion it is assumed throughout that the technical problems of toll collection can be solved at favorable cost), no resources have been used and society has lost nothing. The tolls simply transfer income from users to the government. It will be redistributed in one manner or another: perhaps general taxes will be cut; perhaps general governmental services will be improved. All that will have occurred is a "costless" transfer of income.

Such is the happy outcome that "social costs" have been converted into community income with no exhaustion of real resources. If there has been no response to charging a toll, no individual has gained, but society has not lost. If there is any response, the toll payers are unequivocably better off. The toll charge, as one advocate blithely remarks (5) is "a transfer payment involving no net loss to the community (i.e., the rest of the community gains what the vehicle loses) and therefore can be disregarded." Because the toll charge is seen merely as an instrument to bring about a reduction in traffic which is thought to be beneficial—and an instrument which tends to remove the right users—writers have been wont to hurry nervously over this subject, as though it were a minor irritation, leaving to politicians the task of explaining to toll-payers the "costlessness" of their loss of income. (Politicians might also have to explain why users should pay "costless" money for social costs they inflict upon others, but should receive no compensation for the social costs that others inflict upon them.)

The Marginal Cost.—Actually, a more thoughtful view of the matter shows that the social cost theory need not regard toll charges as being "costless," but rather as legitimate prices based on marginal cost which ought to be charged. Welfare economics suggests that the individual motorist should not be permitted the option of choosing more congestion and no toll charge, except in the far-fetched case that no user put any value on faster, safer, and more confortable travel. The existence of congestion

creates the obligation to pay. Obviously, this theory involves much more than the idea that pricing is an apt way to restrict traffic and control highway use. The economic principle on which the theory rests is fundamental: price should be based on marginal cost, to achieve the best organization of the economy. With marginal cost prices, nobody will consume a commodity that he values less than it costs to provide, and the value of all goods and services rendered by the economy will exceed by the largest margin possible the cost of supplying them. This principle applies as much to highways as to any other activity where price policy is in question. If social costs are clearly a consequence of added road use, the marginal cost criterion indicates that the benefit to each user should be as much as the cost imposed on fellow users (and any others).

All of this accords with marginal theory; but the marginal cost criterion is not blindly accepted as a welfare principle in the economic world, and some of the questions concerning it are important here. Marginal cost is considered mainly as an explanation of "short-run" pricing decisions. Prices are set at the marginal cost level to achieve the best use of facilities. If prices do not influence use, the pricing basis is indeterminate, except as a guide to "long-run" economic behavior. Marginal cost prices that produce revenues greater than total costs will stimulate plant expansion and attract entry into the enterprise. Marginal cost prices which result in deficits will induce contraction and withdrawal. In short, time is expected to correct over-use or under-use; at least there will be a constant tendency toward best use.

The case for marginal cost prices that produce revenue surpluses or deficits over the long run is much less certain, and is the subject of intense economic debate. Enterprises with marginal costs below average costs would have to be subsidized to remain active. Activities with high marginal costs (greater than average costs) would earn excess returns. Marshall's suggestion of a "tax-and-bounty" system of pricing, whereby excess returns are preempted by the community for the purpose of subsidizing long-run deficits, is relevant to the pricing of the lightly and heavily used links in a highway system.

In a word, marginal cost is not an infallible theoretical rule for pricing. It must be demonstrated that a gain in social welfare will be obtained from charging prices which produce revenue surpluses or deficits. The highway case calls for particularly close analysis; this is not a case dealing with the simple substitution of one good or service for another. Nor is one dealing in this context with "costs" that have been incurred by any but the users themselves. There must be consideration of whether a positive gain might actually be achieved by pricing these costs.

## FOR WHOM THE TOLLS TOLL

How might the results of a rationing toll policy be evaluated in practice? Let it be supposed that on a congested highway a toll charge has been levied and free-flowing traffic movement restored. The highway authority desires to learn whether a net gain has been achieved. How would it reckon up the gains and losses that had occurred?

At the outset, it is assumed specifically that there will be losses which deserve consideration. The attitude of those who are panicked by the growing flood of automobile traffic into thinking that any rationing of traffic is good per se is not adopted. Rather, it is insisted that the losses of those forced by tolls to consider inferior alternates be balanced against the benefits to those who remain and pay tolls.

### The Tolled

Who are the gainers from restrictive tolls? In general it would be desired that those tolled would stand to benefit most from the improvement of road service—that is, they would place the higher values on time savings, comfort and convenience, safety, and other service factors. More exactly, these users would include the following groups:

1. Motorists who had a pressing need to move rapidly but were unable to foresee the need to take a trip. In this category would be emergency calls for ambulances and fire trucks and other such irregular traffic desires.
2. Motor vehicles carrying larger numbers of passengers. Express buses would have to be credited with a high value on rapid movement because the value would

represent the total demand of all riders in the bus. Car pools would also be in this class.

3. Motorists willing to pay for "luxury" service. Many students have felt increasingly that the ownership and operation of automobiles in metropolitan areas is a costly privilege, that this privilege might be reserved for those who can afford to pay for exclusiveness.

4. Motorists who have no convenient choice but to use a congested road. Because they are "captive" users to a large degree, they cannot easily disengage themselves if road service is not to their liking; thus, they may have a special interest in good service.

This list is not complete, but it suggests the nature of the gains. It points up that there may be considerable variation in the way that individual users would value the gains, which in turn depend on different motives for traveling. In the usual analysis of highway benefits, average values are given to highway service factors, which permits the evaluation to proceed but is not altogether satisfactory. This becomes evident when an attempt is made to value the gains of traffic restriction. The problem might be solved if the toll charge itself measured the gain, but it does not.

Most analyses of toll rationing concentrate attention on the comparison of travel time "before and after" decongestion. As a typical example, one may look to Tanner's verbal illustration (5, p. 1). On a given facility, 1,100 users during a given time period are reduced to 800 by a sixpence toll. The 1,100 traveled only 10 mph; the 800 travel 15 mph. Each user's individual time cost for the given trip was assumed to be 10 pence when travel was at 10 mph. For the 800 who remain to pay the toll, the individual time cost is reduced to 6.67 pence. Each user saves 3.33 pence, for which he pays a sixpence toll.

For the moment the fact that this appears to be a bad bargain for the toll payer is ignored. Instead a look is taken at the 300 who would not pay the toll. Each of these is unwilling to invest the 6.67 pence in individual time cost, which he would incur by using the decongested road and the sixpence toll. Thus, their value on using the road, although high enough to have made them endure 10 pence of travel time cost, is less than 12.67 pence.

Several points concerning the valuation of time, as used here, deserve comment. First, it may be noted that the time dealt with is generally regarded as leisure, that is to say nonworking time. This seems reasonable because such time is probably far more significant than working time in the usual congestion situation; it is also far more difficult to deal with in economic terms.

The second point is that in the typical analysis time values are established independently. One method is to equate leisure time with take-home wage rates. As something of a digression, the authors raise an eyebrow at this.

With working hours set institutionally for the most part, and with fairly short workdays and workweeks, there would seem to be reasonable doubt that individuals value nonworking time at wage rates. Witness the vast expansion of "do-it-yourself" work which involves an investment of individual time very often at returns much less than the do-it-yourselfer's wage rate. It may be said that time used in such activity is not lost but is part of leisure itself. But, by the same token, it could be argued that transporting one's self in a motor vehicle is a "do-it-yourself" activity, and the time used is not necessarily pure waste.

Time spent in highway travel might be put to constructive use. It does afford change. It can furnish relaxation. It can be part of leisure. It has even been suggested that the driving task itself may be "psychologically rewarding." At least, allowance should be made for the possibility that travel time is less onerous than working time. What this amounts to is that "social costs" of congestion in monetary terms may be much less than the magnitudes often estimated. But use of lower time values would not dispose of other fundamental questions.

Certainly, returning to Tanner's (5) example, none of the users who are diverted from the road can value the time saving—made possible by their decisions—by more than the amount of the toll. Otherwise, they would quickly return. Of those who pay the toll, it is known that their value upon using the road is 12.67 pence or more. This much can be said. But it does not follow from this fact that the value of the time sav-

ing for them is larger than the toll and thus explains why they remain to pay. Indeed, by assuming that all users have the same value upon time saving, a peculiar dilemma is posed: If the toll were equal to or less than the value of the time saving for every user, why would any one of them shift to an alternative? But, of course, if none of them shifted there would be no time saving. And if the toll were greater than the value of any possible time saving to any individual user, why would any one of them remain and pay toll? For it has been necessary to worsen the lot of all users, by 2.67 pence each, in order to shift any of them.

Some users, of course, would continue to pay because the utility of the trip to them is greater than the utility of any other alternative, even after cost has risen a net 2.67 pence. In other terms, it might be said that the net result of the toll (the algebraic sum of the time saving and the money payment), even though negative, is still not sufficient to offset the comparative disutility of the next alternative for anyone willing to pay the toll.

Average time saving values have been used mainly for convenience in exposition. It is recognized in reality that different users have different time values, and hence will respond differently to the imposition of tolls. Thus, it might be imagined that those who had the higher value upon the benefits would be more willing to pay the tolls than those with lower time values—as indeed they would if time savings were the only factor in evaluating the decision to take a trip. One who would pay $1.00 to save 10 minutes could be said to have a valuation on time equal to, or more than, $0.10 per minute. One who would not pay the toll would place a valuation on his time of less than $0.10 per minute. If an average value of $0.10 per minute sufficed to establish the justification for restricting traffic, it would not matter by how much the tollpayer's time saving values exceeded the average—as long as it was thought that they were equal to, or exceeded, the average. (This is simple economic reasoning. No sellers of a product can tell, or need to know, just how much a product is worth to buyers. What matters is that the product be worth enough to equal the price charged. In economic jargon, whatever excess there may be in the value over the price is the consumer's "surplus.")

When the toll proposal has been expounded in general terms, it has usually been implied that the tollpayers will be those more eager for time saving. An oft-made comparison, illustrating the idea, is that of the hard-pressed business executive, whose time is valued in dollars per minute, and the carefree joy-rider, who jogs along mindless of the delays he creates for others and undisturbed by the slow pace. The businessman would gladly pay a price to expel this nuisance blocking his way. The other driver, because he counts little the cost of being slowed by congestion, would be equally unlikely to pay much for the privilege of going faster and would balk at a price. The toll, in this instance, would retain on the road the motorist who had the persuasive reason for wanting decongestion, and would remove the motorist who had no urgent reason to take his trip. The comparison links a high trip utility with a high value of time, and a low trip utility with a low value of time.

But the executive might find himself in competition with another class of motorist, one whose desire and urgency for using the highway compared with his own, but who would have little desire to travel faster if he had to pay for it. The very existence of intense traffic congestion suggests that this type of individual would be present in far greater numbers than joy-riders. The tenacity of the typical urban commuter, driving in traffic congestion that would be discouraging to almost any other travel purpose, attests to the utility of his trip. And this is small wonder, for the journey to work enables him to earn his living. Now the commuter might have a value upon time saving that was above or below the average; his evident willingness to pay a toll would by itself give no clue to this. What can be said for certain is that, if there is no convenient alternative to the highway for going to and from work, it would take an imposingly high toll to make much of a dent in rush-hour traffic. The business executive might give up in disgust, rearrange his hours of work, or even move his office to the suburbs before paying tolls that provided little or no time savings.

Only one case has been found where, considering the congested road itself and the toll charge, the price gives a reliable indication of the value of the gains to the tollpayers. Any driver who has not previously used the highway, and appears when a toll

is charged and traffic volume is reduced, must value the benefits of decongestion at least as much as the toll. A shopper, for example, may have been induced by congestion to use suburban rather than downtown stores. If he is persuaded to travel downtown to shop because congestion is reduced, the gain to him equals or exceeds the price he pays.

The essential reason why the rationing toll fails to reveal much about the value of the gains from traffic restriction is that it does not ordinarily offer the tollpayer a true "before-and-after" evaluation. If a 10-min time saving is achieved by charging a $1.00 toll, the typical motorist does not have the easy option of paying to save the time, or not paying and receiving no benefit. Only if there is an alternate travel route which required the same travel time as the congested road before the toll was charged, and afterwards takes 10 min longer, does the toll give an "either-or" choice. If the alternate to paying roughly simulates the "before" situation, the motorist can exercise his opinion about the road service improvement, for if he elects not to pay the toll, he will at least be no worse off than before it was charged.

Otherwise, the benefit values represent an independent judgment of the analyst. And there is danger that his discretion will establish a self-fulfilling condition. The higher the price it may take to remove a vehicle from a congested road, the greater may appear to be the social cost of the congestion and the greater the saving in this cost from reducing traffic; hence, the more justifiable the toll.

## The Tolled-Off

There is, in fact, little said in most analyses of toll rationing about those who choose not to pay the toll. It has been noted that their valuation on the trip via the tolled highway must be less than those who pay the toll. It also has been indicated that they have found an alternative. Now, it must be noted that the tolled-off user prefers the facility with congestion to any alternative he selects. The toll has motivated him to use a less desirable alternative and to incur a loss. Although it might be concluded that the loss cannot be larger than the amount of the toll payment (otherwise the user would pay and not be diverted), the main question is whether the loss is less than, or exceeds, the benefits of decongestion.

The following considers a number of alternative choices for those "tolled off" the highway:

1. The Two-Road Network.—This provides the simplest and most defensible illustion of the rationing toll, and it is used frequently to demonstrate the basic theory.

All users travel between points A and B, which are served by two roads, one superior and one inferior. The superior route becomes clogged with congestion. By diverting some users to the inferior highway, a saving in travel time for those remaining can be achieved. If this saving is greater than the increase in time for those diverted, a net reduction of total travel time for all users results. A toll charge will offer a direct choice to users: paying to go faster, or not paying and going slower. Therefore, the toll guarantees that the tollpayers value time saving as much or more than those who are diverted, and any reduction in total travel time for all users can be considered an unequivocal gain. Allowing for different time valuations among users, a toll that caused an increase in aggregate travel time might also be shown to produce a net gain, but the problem then becomes rather more complicated.

The example, however, can be further refined to remove the last shadow of doubt about whether a net benefit is possible. Let it be assumed traffic on the superior highway, before the toll restraint is introduced, increases in volume until travel time is the same as time on the inferior route. Then, anyone who is tolled off the superior highway has not suffered (here it is assumed that there is no congestion problem on the other road), and all those who pay the toll gain. Moreover, the toll charge, because it need be no higher than necessary to keep the diverted users from coming back to the superior highway once a reduction in congestion has been effected, will not be any larger than the value of the gain to the tollpayer. And if the tolled, value time more highly than the tolled off, they will come out ahead, even after the toll is subtracted from their gain.

This is the classic case of a clear gain in economic welfare: nobody is made worse off, some may be made better off, and the "community" has an income which was not previously available. The case is very stringently drawn, but it can serve as a bench-mark from which to view other possibilities.

When the diverted users must incur losses, a reduction in aggregate travel time still indicates that a gain has resulted, but the toll charge cannot be so easily dismissed. Suppose that the congested superior route requires 20 min travel time between A and B, the inferior alternate 30 min. and that a $0.30 toll diverts enough drivers to cut travel time on the superior highway to 15 min. It can be assumed that those who pay the toll value time at $0.02 per minute or more; otherwise, they wouldn't pay $0.30 cents to save 15 min. But they would have to value time at least at $0.06 per minute in order to think the toll payment worthwhile, for they are asked to pay $0.30 to save 5 min over the congested situation. The worse that the alternate choice is in relation to the pretoll situation, the more significant this consideration. For example, suppose the alternate route to require 40 instead of 30 min, and the toll charge to be $0.50 instead of $0.30. The toll informs us that, as before, motorists who pay it must value time at $0.02 per minute or more, because paying the $0.50 toll saves 25 min over using the inferior route. But to be satisfied with having the toll at all, the tollpayers would have to value time at $0.10 per minute, at least five times the amount which their willingness to pay, as measured by assumed time values, seemed to indicate.

Of course, the toll itself has been discounted as a cost because the redistribution of income effected by the tolls is said to benefit all in the community, including those who have chosen alternatives to the tolled facility. The worse the alternatives, the more that this assumption—sure to be questioned as a practical matter—must be relied upon. (Some cities will argue that the whole procedure is inequitable in that it violates ability-to-pay concepts. They will argue that the basic ideas require acceptance of the propriety of existing distributions of income. Most assuredly, the efficiency toll proposal has nonequalitarian overtones. But for purposes of discussion at this point the proposition is here being treated as an impersonal pricing problem.) But there is a further word of comfort for those tolled off the facility. In principle, they might be compensated for their losses out of the income from the tolls. In fact, the tolls required to divert a given number of motorists would not have to be so high if some of them could be "bribed off" with compensation. It can be proved, as a theoretical point, that if tolls in the two-road-network case are used in this manner, then the toll can be made equal to, or less than, the value of benefit to each user who pays, and every motorist's welfare is advanced: the tollpayers receive value greater than price, the losers are compensated more than the amount of their loss. Only the "community" is left out.

The mechanics of compensation are less easily imagined, but the principle potentially has broad application. For example, high tolls could be charged on heavily used highways and low tolls on lightly used roads, which might stimulate some evening out of traffic flow while bringing in the same amount of revenue as with an average user charge assessed equally upon all road use. Or the "bribery" could be indirect. Toll revenue could be used to subsidize rapid transit, which would reduce the losses of those who chose that alternative to the tolled facilities, while at the same time reducing the money payments of the motorists.

2. The Multi-Road Network.—There is no shortage of intellectual apparatus to demonstrate the toll argument as a problem of network flow. Wardrop's (6) fundamental paper some years ago recognized that there are two different distributions of traffic which correspond to (a) the action of all motorists seeking the minimum travel time route between any two points, and (b) the minimum average journey time per motorist, which is the same as the minimum aggregate journey time consumed by all motorists collectively. The first of these criteria explains the network flow that is likely to result from the free interaction of motorists. The second might be brought about by an appropriate toll policy. If travel time is accepted as the measure of efficiency in road use, the second condition could be said to represent maximum efficiency in the use of a highway system.

The multi-road network case differs from the two-road network in that not all users on a given highway are moving between the same origin and destination, so that the same

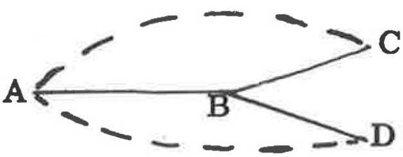


Figure 1.

alternate routes are not equally available. On a congested road, AB (Fig. 1), some motorists are traveling between A and C and have alternate route AC. Others move between A and D and have the alternate AD. Thus, the utility to users of taking a trip on AB will reflect the quality of the alternates. If it is assumed that AC is a very poor alternate and AD is relatively more satisfactory, and if all users are credited with the same value on time saving, those going between A and C would be relatively more disposed to pay a toll charge for AB than those going between A and D. A reduction in total travel time could be achieved if diverting some users moving on ABD to alternate AD would cause less increase in travel time than the saving on AB.

In this circumstance, however, the toll does not guarantee that those who refuse to pay it have the lower value on time saving. The fact that one user's alternate to the best route takes 1 hr longer, and another user's alternate route takes 15 min longer, reveals nothing about how each would value a saving of 10 min on the main route.

Thus, it is possible to suggest that a toll charge could divert users who had the higher value on time saving but the better alternative choice, while retaining users who had a lower value on time saving but a poor alternate. If this is true, the vehicle flow which minimizes aggregate travel time in a road network does not necessarily maximize value in excess of cost.

The foregoing is but a theoretical possibility. However, it illustrates how the evaluation of losses may be complicated by demand factors not directly related to the value of gaining or losing travel time.

3. Smoothing Out the Peak.—Motorists diverted to uncongested time periods, although continuing to use the same route, are asked to accept an inferior time to travel, rather than an inferior route.

The great advantage of network flow evaluation is that gains and losses are measured in identical units. Thus, a simple comparison of physical pluses and minuses may suffice, without having recourse to economic valuation. If time saving, for example, exceeds time loss, it is enough to know that the unit value of time to the savers equals or exceeds the unit value of time to the losers.

For alternatives other than inferior routes, one cannot escape placing some kind of valuation, no matter how general, on both the benefits and the losses so they may be compared. If the pricing objective is to divert users to the off-peak, there is no ready way to estimate the losses occasioned except in terms of the size of the toll charge. Hence, the benefits must also be valued in terms of money.

The success of a rationing toll in achieving this objective depends on the existence of drivers traveling during the peak who have a relatively low value on time delays. A low congestion cost explains why such users tolerate traffic conditions during rush periods and would be responsive to a toll.

4. Car Pooling.—Perhaps the best general case for the rationing toll is the inducement it would provide for highway users to pool their rides. Motorists might be more willing to share each other's vehicles if they could be certain that they would benefit from doing so. The toll charge would provide the necessary instrument to promote the result, and all could partake of the benefits to some degree. However, the losses in this case are almost all in intangible service factors. These include the irritations of conforming to group schedules, the lack of privacy, tensions, crowding, etc., none of which have a quantitative dimension.

5. Diversion to Public Transportation.—The amount of the loss depends on how good a substitute transit is for the automobile, in the mind of the motorist. The choice between modes depends on the proximity of transit routes to travel origins and destinations, the convenience of door-to-door service afforded by the automobile, the reliability of scheduled transport, the value of personal privacy, etc.

It would be possible, of course, to ignore all such service intangibles and consider only the time and cost of public transport. An attempt would be made to determine whether aggregate time and cost could be reduced by a shift of people from automobiles

to trains and buses. Some analysts have urged that making the most efficient use of the transportation system, rather than the road system alone, is the proper objective for pricing, claiming that the "movement of people" may constitute a "higher-level criterion" for defining an optimal solution than does the movement of vehicles.

6. Diversion to Different Destinations.—To grasp this situation, one might rule out all other transport choices, such as the diversion to other highway routes, to different time periods, to riding pools, or to other travel modes. It is assumed that the motorist must either pay the toll or take a trip to or from a different place than he had planned.

Within these limits, the willingness of the user to pay reflects his interest in reaching a particular destination, or departing from a particular origin, compared with others. All manner of theoretical possibilities can be imagined. Giving each user the same value upon time saving, the toll will divert those whose interest is least urgent in getting to a particular place, but the toll tells nothing about how the loss compares with the benefit until an exact value is specified for time saving. It is possible that none of the toll-paying group cares anything about the reductions in traffic congestion. On the other hand, the urgency to reach a particular destination may be directly related to the need for speed, as in the case of a fire engine. Again, it is not impossible that those users with a higher value upon reaching their destinations would be diverted. This could happen if those with the lower trip utility nevertheless thought themselves so benefitted by an improvement in road service that they would pay the toll charge which the others would not.

In short, the losses due to a revision of origins and destinations are fairly indeterminate, apart from the toll. One extremely restrictive assumption is worth mentioning. If it is said that the purpose of a trip is satisfied equally well at any of several destinations, except for travel considerations, then the loss due to choosing an inferior destination is the increase in travel time and cost of going to the alternative.

7. Reduced Trip-Making.—There is no way known of estimating losses in utility when persons are discouraged from traveling altogether.

It would be the objective of a toll rationing policy to "toll off" users until the loss of the last one diverted would equal the gain achieved. But a toll on any particular facility would be likely to produce a wide variety of responses, ranging from a simple change in routing to not taking a trip at all. Although there is some basis for estimating the losses to the tolled off in the simpler cases, estimating losses becomes progressively more difficult and indeterminate as the responses become more drastic. Furthermore, it cannot be ascertained precisely whether a toll will end up in tolling off the very users for whose benefit the toll is charged, while not diverting the user who cares little about saving a few minutes but regards his trip as vitally important.

## How High the Toll?

According to some writings, it would seem that all this bother about comparing costs and benefits is beside the point. Perhaps one has only to avail himself of the principle that price should cover marginal social cost in order to determine a "correct price." It is possible that an estimate might be made of social costs at any given traffic flow, and price set accordingly. (Nothing has been found in the literature to suggest how an economically "correct" toll could be established in practice, other than the general rule that it should be set at the intersection of the demand and the marginal cost curve.)

To see how this theory works out, it is helpful to examine the typical economic diagram for a congested highway as it appears in toll rationing discussions. In Figure 2, all curves are expressed in units of travel time corresponding to a given vehicle flow on a section of highway. The AC curve is average time per user. It rises as traffic flow increases and congestion develops. The amount of increase in the total travel time of all vehicles brought about by the addition of one vehicle is depicted by the MC curve. Any increase (a point on the MC curve) is composed of (a) the marginal vehicle's travel time, as measured on the AC curve, and (b) the delay that the marginal vehicle causes other vehicles, as measured by the difference between the AC and MC curves. This difference is the "social cost" inflicted by one user upon others. Likewise, it is the "benefit" created by the removal of one vehicle.

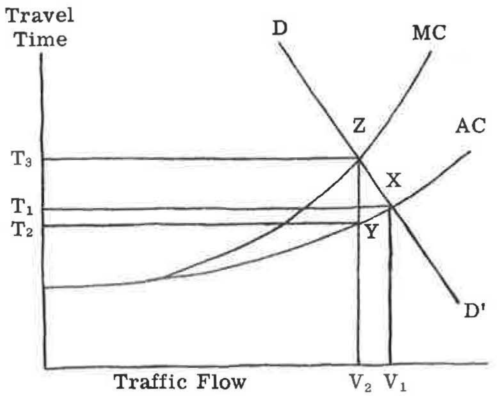


Figure 2.

The demand curve DD' follows from the fact that highway users are responsive to traffic conditions. With increasing congestion and higher travel times, fewer motorists will use the road.

Demand, as represented by the DD' curve, reflects the alternative choices open to users of the highway. To illustrate, suppose that the diagram depicts one road in a two-road network. Travel time on the other road between the points served is $T_3$. Under this hypothesis, the demand curve would be horizontal at the level of $T_3$, because no motorist would have to endure a greater travel time than the alternate route provides. Then assume that the demand curve follows the $T_3$ZXD'. The downward slope beyond point Z has this explanation: if traffic flow on the congested route were $V_1$ and average travel time $T_1$, not all users could be diverted to the alternate route by a rise in travel time above $T_1$. Some would discontinue their trips, changing to public transit, to another destination, etc.

It is evident that the demand curve, as portrayed here, reflects the utility of trip-making on the highway to users, because the behavior of any user willing to endure travel time for the sake of the trip is an index of the value he places on traveling over that road. The loss in value to any user diverted from the road is his total utility, measured by the demand line, minus the actual time cost of travel, which is the point on the AC line corresponding to the volume of vehicles using the road.

Whenever this loss in value is less than the marginal benefit (the difference between the AC and MC curves) created by the removal of one user, the theory argues that economic efficiency can be improved by restricting traffic. Thus, for any traffic flow greater than $V_2$, the gains from restriction will be more than the losses. At $V_2$, the marginal loss and benefit exactly balance. This volume of traffic can be achieved with a toll charge which has an equivalent time value of $T_3 - T_2$. Any user whose trip utility does not exceed $T_3$ would be diverted by this toll. The toll also dissuades any user from coming on the road whose gain in value is less than the added cost, ZY, which he inflicts upon others.

To establish an actual dollars-and-cents toll, of course, marginal social cost, expressed in time units, must be given a money value. Analysts of the efficiency toll proposal customarily transform the diagram in Figure 2 into money terms by multiplying the time units by a given value (such as $0.03 per minute), thus leaving all curves in the same relative positions.

Setting the Toll.—Here one might pause to reflect how the "correct" toll would be set in the real world. Suppose one begins with traffic flow $V_1$. The only datum about demand is a single point on the curve. Nevertheless, to proceed according to the social cost rule, the toll could be set to equal marginal social cost at $V_1$ (the vertical distance between AC and MC). But this toll would be "correct" only if there were no response to it and no benefit produced. Otherwise it would be too high; it would divert more users from the road than could be justified by the value of the gains. Then a lower toll, equal to marginal social cost at a lower traffic volume, might be set and succeeding adjustments made until an equilibrium was ultimately reached. (The path toward equality between marginal gain and loss could be described by the "cobweb" diagram of the firm.)

Rather than juggle prices, a highway authority would probably try to establish a "reasonable" toll in the first instance. This would require a preliminary estimate of the slope of the demand curve under the particular circumstances, which perhaps could best be gained by evaluating alternatives available to users and the losses incident to them. The authority would then determine whether the actual response to tolls fulfilled its expectations.

Evaluating the Result.—What if the toll charge failed to produce the result expected of it? Would the toll authority then decide instead that losses incident to vehicle diversion had been undervalued and conclude that the tolls failed to promote efficiency and welfare?

The easiest case to deal with is the two-road network situation. The difference in travel times between the roads would be given a certain money value, based on an estimate of the "average" users' valuation of a minute saved or lost. A calculation would be made of the amount of traffic diversion to the inferior road required to minimize aggregate travel time. At this point no further reduction in total time could be achieved by diverting one more user. The toll actually charged would be based on the assumed valuation of marginal benefit at the desired traffic flow level. If this toll failed to divert the required number of users, one would conclude that the time unit had been undervalued, not that the loss through diversion to the alternate route was greater than had been supposed. The theory would call for an increase in tolls. In short, in the two-road network example, marginal social cost can be given any magnitude required to justify the toll needed to cut traffic to the desired volume.

In the more general situation where the nature of the demand curve is unknown and no desideratum for the removal of traffic is given, some unlikely conclusions are reached by pricing according to marginal social cost estimates.

A toll authority, seeking to set a price, would pick a value for time saving which was thought to be reasonable. Then by a process of calculation and experiment it would arrive at a toll which would be equal to marginal social cost (at traffic volume $V_2$ in Figure 2). At this volume the toll would equal the marginal benefit believed to occur from the removal of one vehicle.

If demand were highly elastic, the response to a toll would be a relatively large drop in traffic and in social cost. If demand were fairly inelastic, traffic would not drop off as much in response to the toll and marginal social cost would remain relatively high. These different responses are depicted in Figure 3. In each case, the toll charge is $T_3-T_2$, the benefit to tollpayers is $T_1-T_2$, and the reduction in traffic is from $V_1$ to $V_2$.

When demand is inelastic (Fig. 3b), it takes a rather large toll to produce a small benefit. In the other instance (Fig. 3a), a smaller toll (smaller because marginal social cost at $V_2$ is less than in Fig. 3b) produces a relatively large benefit. An interesting corollary is that a toll that completely restores free-flowing traffic conditions would have no justification on the basis of social cost. On the other hand, the highest justifiable toll would be charged when demand was totally inelastic (the curve would be a vertical line) but no benefit at all would be gained from its imposition.

An elastic demand suggests that alternatives to trips on the road are readily available and their comparative disutilities are not great. A toll charge then gets results. An inelastic demand suggests that the disutility of alternatives is great and that little is to be gained by charging a toll. Yet the social cost theory claims that in this latter situation an even higher toll ought to be charged.

Here one begins to appreciate the theory's need for the crutch that the tolls are "costless." The social cost theory begins by assuming that tolls equal to marginal

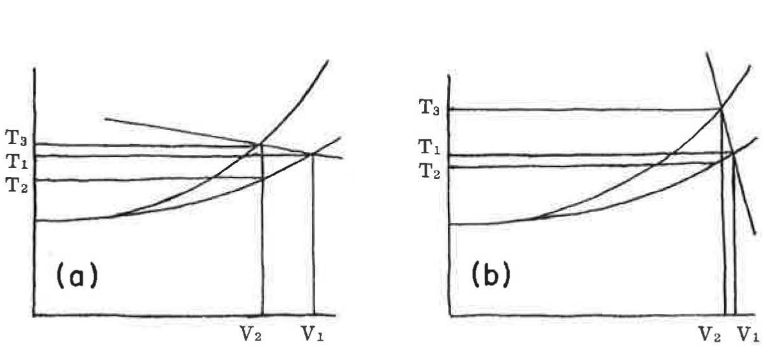


Figure 3.

social cost at any traffic level are justified. Thus, any response to a toll which equals marginal social cost can be counted as a net gain, for the toll revenue remains in the community and represents no loss of value to society. But surely this is a slender thread upon which to hang an entire theory of pricing and income redistribution.

Allowing for Different Benefit Values.—In Figure 2, it is seen that the toll charge, $T_3-T_2$, is larger than the reduced travel time to each user, $T_1-T_2$. The best that can happen to a tolled motorist is that he will be no worse off after the toll is paid; but the demand curve would have had to be horizontal at the level of $T_1$ for this solution. Otherwise, the toll would necessarily leave all motorists in a worse position, in order that any might be diverted. Only "the community" can gain from a restrictive toll policy, given the assumption of a uniform value on the time unit for all users.

This assumption is made, as previously noted, primarily as a convenience in presenting the toll theory. Of course, one might assume that those who pay the toll have the higher value on the benefits it provides, and would think themselves better off even after the toll payment. But we have discovered no proof of this result through a rigorous use of social cost theory. Indeed, the theory does not rule out the opposite result: that those with the lower value on benefits remain to pay because they have the more intense trip demands. Even then a net gain might be shown, as long as the value of benefits exceeded the loss in utility to those diverted. But in this event, it is essential that the toll charge deprive those who pay it of any benefit they gain—and by a considerable margin—in order to keep those diverted from coming back on the road.

## The Untolled

At this juncture, consideration might be given to the impact on still another group—those who are already using the alternatives to which some of the former users of the toll facility shift. One can easily visualize a number of situations. For example, alternative facilities might have ample capacity so that no new social costs would be created as a result of the transfers. (This was assumed in the simple two-road network case.) On the contrary, greater utilization of an alternative (a transit route, for example) might actually reduce the average costs of providing the service and stimulate better service, which would reduce "social costs" of all who use it by reducing waiting times. On the other hand, if the shifts were made to certain other facilities (previously uncongested highway routes, for example) it is possible that congestion would begin to build up there and a new epidemic of social costs would be encountered.

At this point, one suffers mental indigestion trying to picture the tolled, the tolled-off, and the untolled, the users and the nonusers, bouncing around among the alternatives, all the while a blinking giant of a computer is fixing and refixing tolls, shadowing users, and redistributing income to promote the general welfare through an optimal arrangement, not only of travel, but also of nontravel.

Yet one more thing must be said about social costs and gains. It is assumed that the private gains to those paying tolls are greater (or no less) than the private losses to those using alternatives. But the original case for efficiency tolls was based on a finding of social costs for which prices should be laid. Hopefully, tolls will have reduced social costs somewhat or caused them to be converted into community income. But what of other consequences resulting from the rearrangements of travel and living patterns which have been wrought by the tolls. In short, one must ask whether the removal of users from congested facilities may result in hitherto unmentioned social costs or, for that matter, social gains.

Economists do not often carry the argument into this field. Yet one suspects that many who flirt with the efficiency toll proposal hold the thought that anything that may discourage highway travel will be socially good. Thus, tolls might be useful regardless of the underlying economic rationale; the economic concepts of "social costs" and "costless transfers" are conveniently available to bolster the case (or to obfuscate the issues).

Space does not permit of joining the attack on this new battleground. One can simply pose the question: possibly a discouragement of highway travel will result in significant losses in preexisting external economies, bring about less desirable living conditions, or even create a less rather than a more viable and amenable urban structure. The

case for toll rationing cannot be closed without acknowledging the possibility of adverse as well as beneficial social consequences. No economic calculus, presently available, is known which could balance all of the gains and losses, the private as well as the social.

## HIGHWAY EXPANSION VS TOLL RATIONING

The question that will have occurred to highway engineers, and perhaps everyone else, throughout this discussion is this: Why, if congestion is so bad, is not highway capacity simply expanded in order to eliminate "social costs" by providing for free-flowing traffic. The answer, stated simply, is that it is vital to the pure logic of the toll rationing proposal that capacity will not be added, because it is (a) impossible, (b) uneconomic, or (c) undesirable to do so. Physical or technological impossiblity of expansion will be extremely rare. The other cases go to the heart of the matter.

### Rental Tolls

An instance of uneconomic expansion of the highway plant would be one in which the cost of an added facility through a traffic corridor would be so great that informed users would not willingly bear the actual costs of a particular investment (even notwithstanding its contribution to "the system"). With increasing land and construction costs in urban areas, it is quite conceivable that a new facility could not now be economically justified, even though an existing facility which has now become congested was warranted when built.

Whether or not it would be "undesirable" to expand highway capacity involves a more difficult judgment, part of which is beyond the ken of the economist. It might be found by planning decree, for example, that highway expansion would seriously diminish some specific community value, perhaps an esthetic view. On a broader scale, intersubjective community agreement might hold that continued catering to the effective demands of highway users would adversely affect city form. Obviously, important trade-offs are made in such planning decisions.

The costs and benefits of highway expansion should be included among the data to be weighed in the planning process. But the relevant costs will be the actual costs of highway expansion rather than the social costs inflicted by congestion. In fact, costs of congestion will be entered on the other side of the equation; their elimination will be shown as benefits to be offset against actual highway costs. Only after a planning decision has been reached against highway expansion would it be pertinent to evaluate the conversion of social costs to community income through toll rationing.

In this event, the pricing of social cost becomes a long-run proposition, and tolling brings a permanent return to the community in excess of actual expenses. How could these profits on a public service be satisfactorily explained? The question might be turned around to ask, as Kuhn (7) does, why users should be charged any less than they could be charged—why should there be any discrepancy between the potential and actual revenues earned by a public enterprise? Obviously, highway users, by and large, could be made to pay much more than they do.

Although Kuhn observes that there are a wide variety of motives involved in pricing decisions for public enterprises, it may be set down as a general presumption that government will not attempt to exploit a monopoly position without good reason. Thus, the rationale of a long-run excess return from highways must be that the excess is properly earned as a "rental" for resources which, for natural or artificial causes, are in fixed supply. As Lewis (8) puts it:

> If marginal cost exceeds average cost, there will be a profit. This profit is a rent for the use of some scarce resources owned by the undertaking. For example, suppose that the road system can be extended only at rising marginal cost; then if the government based motor taxation on this marginal cost it would probably receive each year a sum well in excess of its expenditure on roads. The difference is a rental for the use of existing roads, and is a very proper and necessary charge if road transport is not to develop beyond the economic point.

The concept of "rent" is usually associated with the pricing of land, but its application in other economic sectors—and specifically to the pricing of highways—has long been recognized in basic economic literature. Knight (9) offered the two-road network case to illustrate the rental charge due to the owner of a superior opportunity for investment. The "toll or rent" on the superior road, he said, would be adjusted to just the amount a user would pay rather than use the inferior road. This adjustment, he demonstrated, would be the one that would maximize the total product of both roads.

In general: "The point is that any opportunity, whether or not it represents a previous investment of any sort, is a productive factor if there is sufficient demand for its use to carry into the state of diminishing returns the application to it of transferable investment. The charge made by private owners for the use of such an opportunity serves the socially useful purpose of limiting the application of investment to the point where marginal product per unit is equal to the product of investment in free (rentless) opportunities; . . ."

Nevertheless, the analogy between rent for land and rent for roads deserves close inspection. The economic rationale of land rent is this: since the same piece of land cannot be used for more than one purpose, the rental charge assigns the land to its most valuable use—that which will pay most for locating on the land. It is implied that the rental charge forces a choice between one use and another. But land is capable of combining two or more uses if they are not thoroughly incompatible. Even though the uses interfere with each other to some degree, like an apartment over a laundromat, each user might think himself better off by sharing the site than by paying for exclusive occupancy. The fact that a user would be willing to pay the full rental for exclusive occupancy, rather than not occupy the site at all, tells nothing of his attitude about joint use. The landowner might decide that he could get his greatest return by limiting the site to one user, and excluding the other, without this arrangement being in accord with the private wishes of either user.

In essence, if a highway is a scarce resource, it is also one that may be jointly used. The toll proposal is designed to reduce the amount of joint tenancy. A toll may make the gain from more exclusive use of the road larger than the loss to those who are denied use. On the other hand, it might leave all users dissatisfied because they would prefer to endure each other in order to avoid tolls. The "rental" rationale for the toll, in short, does not escape the evaluation of welfare gains and losses which has already been explored at some length.

Short-Run Tolls

Some economic theorists who embrace sophisticated pricing techniques will take exception to the conditions just laid down. Some regard efficiency tolling only as a temporary expedient. They see inadequate highway capacity as a short-run phenomenon and would improve the "efficiency" of highway operations by toll rationing until "adequate" capacity can be provided. It would be an incidental but welcome result if the tolls were to provide revenue for additions to capacity.

No overriding virtue is found in this approach. The questions that have been raised and the reservations that are held about tolls over the long pull apply with equal force to short-run tolls. In fact, they are somewhat reinforced by the feeling that short-run tolls are likely to be quite capricious, penalizing some users for the benefit of others because of faulty planning for which none of the users was responsible. The "temporary" nature of such tolls would make it difficult for anyone to make a rational adjustment in travel or living patterns.

The only real difference introduced here is that highway expansion becomes part of the toll package. The basic question is whether the result would be any different than under a rational use of more conventional financing methods, whereby funds would be borrowed, the facility built, and tolls or prices collected to repay actual costs. If the result of the toll approach were no different, it would seem that theoreticians are straining themselves unduly to provide an esoteric rationale in terms of social costs for a fiscal policy that can be handled straightforwardly.

## Efficiency Tolls as User Charges

There is a school of thought, however, that feels the need to rely on the social cost theory in order to justify any highway prices at all (other than for current maintenance and operation). Included in this school are some whose thinking is far from "anti-highway"; in fact, they sometimes chide engineers as being too modest in advancing the case for highway expansion. This school uses the economic reasoning whose description has been attempted to demonstrate that capacity should be added to the plant. They would use tolls to convert "social costs" into highway income which would be used to eliminate "social costs," thus to create benefits for users and for the community-at-large.

Here the main departure from traditional reasoning is the insistence that only the "social cost" theory justifies the imposition of sophisticated user charges which will provide revenue for capacity expansion. This notion stems from the reasoning that investment in all segments of the existing highway plant is sunk. Thus, the only justification for any user charges in excess of current operation and maintenance expenses must rest on a finding that the social welfare will be advanced by such charges.

The genesis of these ideas is to be found in cases discussed by leading welfare economists a generation or two ago. In striking contrast to modern times, the typical examples involved over-capacity (or under-utilization). In a toll bridge example, for instance, it could be demonstrated that welfare would be promoted if the toll were removed, because additional traffic would impose no costs on anyone; there would be neither additional highway costs (the average would decrease), nor additional user costs (without congestion the average would stay the same).

As a change is made to the case of under-capacity (over-utilization), the reasoning is turned around. Additional traffic still does not increase highway costs (indeed, it reduces average costs), but it does increase the costs—the "social costs"—of all users. Tolls which would reduce traffic would reduce these costs or convert them to revenue which would be available for highway expansion.

This line of reasoning has promise, but it may be impossible to demonstrate that the revenue earned by such a toll structure would provide for just the "right" amount of highway expansion, without the use of some extreme assumptions. Where demand is highly elastic, returns will be meager, and where demand is inelastic returns will be handsome—even though the cost of highway expansion might be the same in either case. The failure of congestion to build up on roads might bring in considerably less revenue than necessary to finance warranted road improvement. In addition, amounts of revenue produced would depend somewhat on values placed on benefits, and thus on social cost. The higher the unit value of time saving, the more would be total revenue. Or if the unit value of time were derived from an estimate of total revenue requirements, what is accomplished that is not accomplished by straightforward user financing?

A stronger argument for a varied price structure might be made if the road system were regarded as an interrelated network, so that the effect of charging high prices on congested roads would be to stimulate the use of lightly-traveled roads. In a road network situation, however, tax surpluses on some roads would be used as subsidies for others, and marginal social cost might not then serve as a satisfactory guide for correct price levels. A certain theoretical logic may be dug out of all this, but the concept of "social cost" in a multi-road situation needs more elucidation than it has had to date before it can be considered as a reliable basis for pricing.

## Improving the Conventional Approach

Conventional highway financing, with its concentration on actual highway costs, can be made to produce satisfactory results.

It is now assumed that there is going to be provided capacity which will eliminate social costs "within reason." But the "costs" are looked on as the "benefits" of highway improvement. Highway investments are made accordingly. Through prices the amounts required to amortize investment costs and pay for current maintenance and operations are recovered. No reason is found to effect a redistribution of income from highway users to others in the community, or from others to highway users.

Obviously the model is oversimplified. It may not be possible to balance capacity and demand precisely. In some cases, indivisibilities of construction will require provision of too much capacity. In other cases, miscalculations in planning will result in over- or under-capacity. These are part of the risks of highway investment planning that must be borne by someone. In this case, why not by the users themselves? It might be said that a risk factor will be included in the costs assessed against users. Where there is under-capacity, the risk cost will be manifested in increases in users' time costs.

It should not be thought that present practices of highway finance are condoned on grounds of economic theory with its nearly uniform pricing structure over time and space, and the geographical cross-subsidies inherent in current expenditure policies. On the contrary, there is a strong appeal for greater sophistication in pricing policy and for advanced techniques of revenue collection. In fact, the end result of this thinking might look almost as though the efficiency toll argument had been embraced.

For example, close study of actual highway costs would unquestionable reveal a case for differential charges (call them tolls) during periods of high traffic demand. Thus, if capacity were needed simply to take care of weekday commuter loads on an urban freeway, the users during the peak period should pay for that capacity. Similarly, if a mountain road had to be expanded only to accommodate week-end travel, appropriate charges to the responsible traffic would be in order. But in each case the differentially higher charges would be based on actual costs rather than elusive social costs.

What is suggested here is not at all unconventional. In fact, it follows directly from the incremental cost theory which appeals to engineers as the "scientific" or "engineering" solution of familiar highway cost assignment problems.

To oversimplify an analogy: If it takes 4 in. of pavement to accommodate passenger cars, but 6 in. to accommodate trucks, the increment in cost (that is, the cost of the 2 in.) is assigned entirely to the trucks. But they are also to bear a share of the costs of the initial 4 in. of pavement, as well as a share of costs which are nonincremental in nature (such as right-of-way costs). Now suppose that four lanes of pavement are adequate to handle all traffic through a corridor except during given peak periods; and additional two lanes are needed to provide "reasonable" flow during the peaks. Peak users would be called upon to pay for the additional two lanes plus an allocated share of the basic four-lane facility.

It is not proposed in this paper to go into the nature of the added highway costs, nor how they, as well as basic costs, might be assigned. It is pointed out, however, that all evidence thus far indicates that additions to cost are less than proportional to additions to capacity for individual freeways. In other words, a six-lane facility costs less than 50 percent more than a four-lane freeway; eight lanes cost less than one-third more than six lanes. On the other hand, if an entirely new freeway were to be required through a corridor to handle peaking its costs would likely be proportional to, or perhaps even higher than an original facility which could handle off-peak traffic.

The important thing is that there are peaking costs which ought to be identified, measured and brought out into the open for evaluation. If these costs were brought home to peak users through prices, one might expect some responses not unlike those expected from efficiency toll pricing, but the case would be based on the solid foundation of actual highway costs assessed against those who gave rise to them.

It is concluded that a case for more "sophisticated" pricing of highways may be made without resting it on an elusive "social cost" or "costless transfer" line of attack. In fact, the typical case for efficiency tolls, notwithstanding the usual impressive mathematical convolutions, appears to rest on a remarkably "unsophisticated" line of reasoning.

A case may be made for differentiation in highway pricing based on geographical and temporal differences in highway demands in relation to carefully measured, but actual highway costs. Such pricing would make for more accurate appraisal of the effective demands of users and provide the wherewithall with which to meet them.

To go beyond this, however, and to base a system of pricing on social costs as measured by congestion alone leaves many questions. The social cost theory would have prices charged for congestion costs regardless of benefits that result or losses that

ensue. Prices are not charged for service improvements. Actual prices may be unreasonably high in relation to benefits. High tolls could provide luxuries for some while denying necessities to others. On the basis of social cost theory, there is no conviction that the results of vehicle rationing through tolls would be beneficial on balance. Therefore, there would be an inclination to let users shoulder their own social costs, in the absence of a showing that efficiency tolls would produce a clear improvement in transportation.

It is not denied that worthy reasons may be found to support attempts at restriction or redirection of motor vehicle use in some urban areas. Pricing might be one of the better tools to accomplish this. But the rationale of a rationing policy should be drawn up in broad planning terms, involving community amenities and esthetics, rather than in the narrow context of social costs which users impose on each other. This requires a balancing of the total consequences of rationing, the adverse as well as the beneficial, not only as they affect users but also as they affect the community-at-large. This part of the toll story seems to remain untold.

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# Congestion Tolls—An Engineer's Viewpoint

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This paper deals with the proposal for adoption, in the central cities of metropolitan areas, of a system of motor-vehicle taxes or tolls commonly known as congestion tolls, based on the concept that the marginal costs of congestion (operating, time, and accident costs resulting from congested traffic) should determine the magnitude of user charges.

The concepts of marginal-cost pricing and their particular application to government-provided services are reviewed and the fact is brought out that numerous economists do not regard highly this method of pricing government services, and even call into question the primacy of marginal costs as a determinant of prices in private industry. The formulations of those advocating congestion-cost pricing are then reviewed and discussed. Some exceptions are taken, both to the reasoning employed and to the handling of data.

Various implications of congestion-cost pricing are considered. The contention is advanced that a model relating benefits, costs, and prices in the form of user taxes and tolls should be a dynamic model, taking account of variations over time, rather than a static model expressing only the relationships existing at one time. The current status and prospects of urban highway finance are examined, and it is concluded that the existing combination of Federal and State user-tax revenues with local revenues, both user and nonuser, is adequate and efficient for the purpose of financing programs of highway and street improvement. Examination of the nature of urban highway traffic, evidences of improvement in travel times and average speeds resulting from completion of freeways and improved traffic engineering, and prospects of further improvement, indicate that congestion tolls would make no significant contribution to solution of urban congestion problems. Income effects are discussed and it is shown that congestion tolls discriminate against the low-income motor-vehicle user. The point is made that the effects of congestion tolls on business, whether favorable or unfavorable, are a part of the total complex of benefits and costs to be considered in making a decision. Finally it is pointed out that the imposition of prohibitive taxes on motorists at the city center could well defeat the alleged purpose of congestion tolls, by causing both workers and business to seek outlying locations not burdened by such charges.

In view of this series of adverse findings it is concluded that congestion tolls do not promise to make a significant contribution to the solution of urban congestion problems.

•IN RECENT YEARS certain ideas about highway user charges, by no means new in themselves, have been presented with greater urgency than in the past and with a

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persuasive plea of timeliness, particularly in urban transportation financing. These ideas relate, first, to the determination of user taxes or toll charges on the basis of marginal rather than average costs, and second, to the proposition that the extent of congestion caused by the use of the highways should replace public outlays for highways as the principal determinant of the level of user charges.

Because the adoption of highway financing policies based on these ideas might bring about marked deviations from present practices in user taxation, the question of their soundness and adequacy is indeed timely. For this reason a panel session of the Highway Research Board was organized to bring the ideas of so-called congestion pricing before a suitable forum and subject them to discussion from a variety of viewpoints.

This paper is written from the standpoint of the highway engineer or official having the responsibility of planning or administering highway programs, including their financing, or of participating responsibly in such activities. To attempt a treatment of the subject from this angle is in itself a formidable task, inasmuch as highway engineers and officials hold a wide variety of views. There is, however, some unity in the engineering approach, and some consistency in the ideas which engineers and highway officials bring to the solution of the problems that confront them. The progress that has been made in highway research and planning over the last 30 years, together with advances in the arts of highway construction, maintenance, and operation, form the background of this attitude. Although it is believed that the highway engineer is by no means impervious to economic and social considerations, the treatment here does not attempt to grapple directly with the economic principles and mathematical formulations that underlie the theory of congestion charges or tolls. This work is left to the economists, except for some descriptive treatment and the citation of comments by a number of economists.

## THE FORMULATIONS

To understand the ideas involved in congestion-toll theories, it is necessary to present and discuss some of the economic concepts involved and at least some of the simpler mathematical formulations with which they are supported. Only the more elementary formulations, the first steps, so to speak, are dealt with here, inasmuch as to elaborate these theories would be not only to copy the presentations set forth by the economists, but also to attempt demonstrations outside the competence of the writer. Beyond the presentation of the simpler formulations this paper merely states the directions and steps in the more advanced development of these theories.

### Marginal Costs of Highway Provision

There has long been controversy as to whether the financial support of highways and other publicly-provided services should be determined on the basis of average costs or marginal costs. It is true, of course, that costs must be met in some way, and in that sense the financing must be on the basis of average costs. The question at issue, however, is that of user charges. Many economists contend that benefits are maximized and the economic allocation of scarce resources is served when charges to users of a service are based on marginal costs.

Marginal Costs Under Perfect Competition. —The marginal-cost principle can be illustrated by citing the example of a commodity of which 500 units can be produced for \$30 and 600 units for \$33. The average cost of the 600 units is \$0.055, but the cost of the additional lot of 100 units is only \$0.03 per unit. Marginal cost is commonly expressed as the cost of producing one additional unit, but the idea is conveyed by the example.

Figure 1 shows the essential cost-price relationships involved in the operation of a firm under perfect competition. Curve AFC is that of average or unit fixed costs. Because total fixed costs are, by definition, constant in the short run, the product of output and fixed costs per unit is a constant, and the curve is a rectangular hyperbola. The curve of average variable costs, AVC, is typically U-shaped. For example, when a plant is running well below capacity employment of both labor and equipment is likely to be inefficient in terms of cost per unit of output. As capacity

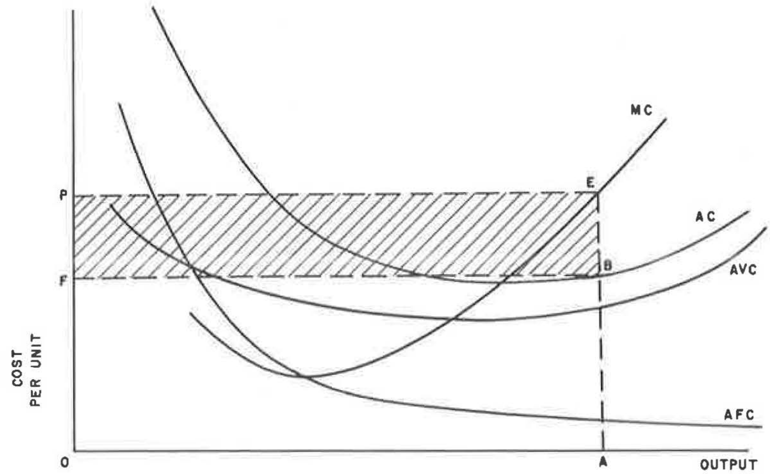


Figure 1. Short-run cost curves and price-output relationships under perfect competition.

is equaled or exceeded a point of maximum efficiency is reached and average variable costs begin to rise. The average total cost curve, AC, is of the same shape, but reaches a minimum at a point to the right of that of the average variable cost curve. The curve of marginal cost, MC, the cost of producing one additional unit at any given volume of output, is also U-shaped, but of sharper curvature, reaching a minimum at a point to the left of the minima of curves AVC and AC, and passing through those minimum points.

For a single firm the price is given—i.e., fixed by the market. In Figure 1 price is represented by OP. If output is set at OA, the point where price equals marginal cost, the firm will operate at maximum profit: if more units are produced the price will not repay the cost of producing them, and if less units are produced there will remain additional units that could have been produced at a profit. The total revenue of the firm is represented by rectangle OPEA, total costs by rectangle OFBA, and net profits by shaded rectangle FPEB.

Under different market conditions the price may be such that the firm cannot produce at a profit. If, however, the price is less than total cost but more than variable cost, output set at the point where marginal cost equals price will produce net revenues (excess of total revenues over variable costs) that will cut loss to a minimum. In the long-run condition fixed costs become variable and curve AFC disappears. Normal profits are included in the cost curves. Output is set at the point where price, P, equals long-run marginal cost, LMC; but, under perfect competition, the price and corresponding output are forced down to the point of minimum average cost, LAC, where average cost and marginal cost are equal (1, chs. 11, 14, 15).

The Case of Highways.—The objective in applying the principles of welfare economics to governmental decision making is to maximize utility, welfare, benefits, or consumers' surplus[1], or any or all of these closely related attributes. More broadly stated, the objective is to achieve an optimum allocation of resources in the governmental and government regulated sector of the economy. One cannot quarrel with these aims. It is necessary to note, however, that both the postulates and the formulations of welfare economics have been the subject of much controversy among economists, particularly during the last 30 years. One is not, therefore, constrained to

[1] If the demand for a product increases as price drops, it follows that there are numbers of people who would be willing to pay more than the market price. A man who pays $2.00 for a product he values at $5.00 enjoys an excess of satisfaction equal to $3.00. Thus the area between the demand curve and the rectangle representing output times price is defined as consumers' surplus.

accept findings and recommendations in this field as given; one can subject them to tests of logic and of applicability to the particular situation or problem.

Public enterprises and public utilities subject to governmental regulation have the attribute that prices are not set by the market, whether under perfect or imperfect competition, but are determined by government or under government surveillance. A second attribute common to many of them, of which highways are a prime example, is that of decreasing costs. The fixed costs of the existing plant are so great in relation to variable costs under most circumstances that marginal costs, in the normal range of use, are decreasing, and often very low. The cost, in public outlay, of admitting one more vehicle to the traffic stream on a highway is imperceptible; nor is any measurable cost incurred in admitting one more passenger to a railroad train.

Ordinarily the setting of prices in such an enterprise is governed by the necessity to recover the expenses of capital charges, maintenance, and operation—i. e., average costs. Welfare economists contend that utility will be maximized, even in this situation, by setting prices equal to marginal costs. Figure 2 shows the case of an enterprise with decreasing costs, which for the present purposes may be taken as representing the operation of a highway system. Output may be taken as vehicle-miles of highway service. Marginal costs are less than average costs within the entire range of the chart. The demand for highway services is represented by line D.

It is held that utility will be maximized if prices are set at the point where the demand curve intersects the marginal cost curve, MC. If the price is below this point users will be provided with service at less than they would be willing to pay. At a higher price users who would be willing to pay more than the additional cost of a larger quantity are deprived of the opportunity. Output is represented on the diagram by OA, price by OP, and total revenue by rectangle OPEA. Average cost, on the other hand, is represented by OF and total cost by rectangle OFBA. There is, in short, a deficit represented by the shaded rectangle.

The existence of a deficit is held justified by the value or utility of the total service provided, which is measured by the area under the demand curve, OKEA. If this

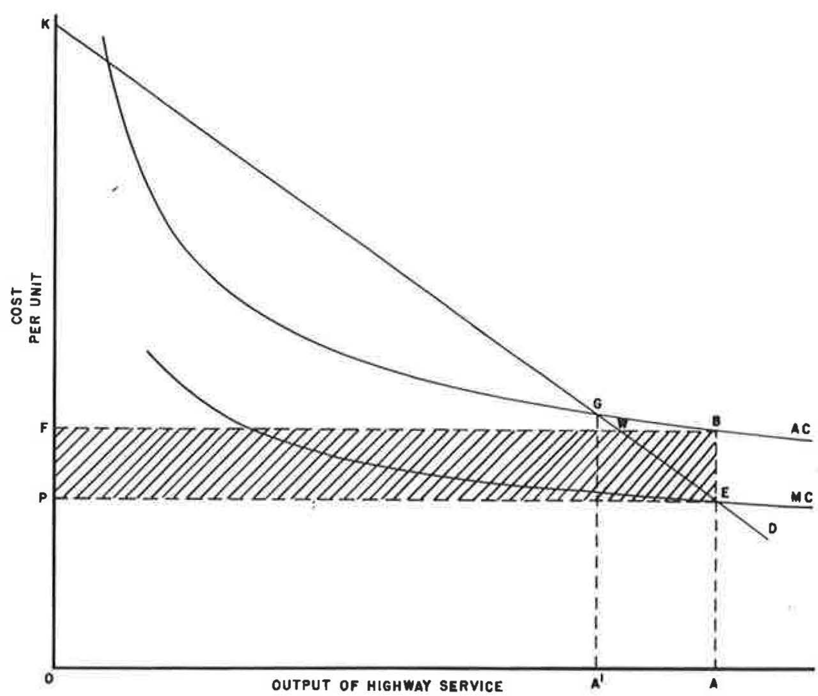


Figure 2. Highways: case of decreasing costs.

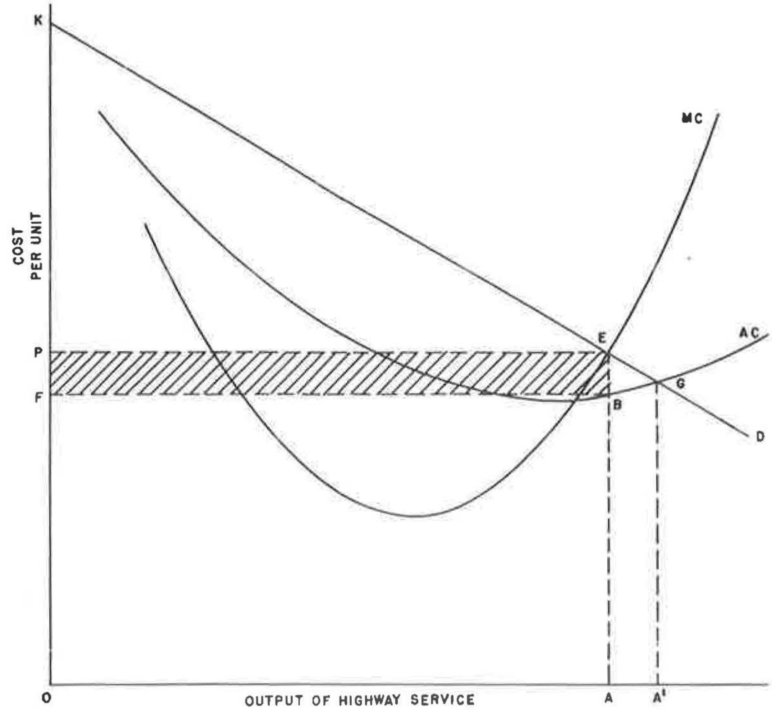


Figure 3. Highways: case of increasing costs.

area exceeds the cost, OFBA—or, cancelling areas common to both, if FWK exceeds EWB—the pricing is justified under the concept of consumers' surplus. The problem of overcoming the deficit remains. If the price is set by point G, where the demand curve intersects the average cost curve, AC, output is reduced to OA′ and the advantages of marginal cost pricing are forgone; but the enterprise meets its costs, with a comfortable amount of consumers' surplus.

Figure 3 illustrates the case of increasing costs, with cost curves much like those of Figure 1. The unit price, OP, is set by the intersection of the demand curve, D, and the marginal cost curve, MC. Total revenue is given by rectangle OPEA, total cost by rectangle OFBA, and there is a surplus. If the price were set by point G, the intersection of the demand line, D, with the average cost curve, AC, total cost and total revenue would be equal, but the added units of output, AA′, would be sold at a price less than the cost of producing them.

From the foregoing it may be reasoned that, in an enterprise characterized by decreasing costs, prices should be set at marginal costs and a subsidy provided to cover the deficit. Conversely, if the enterprise is subject to increasing costs, the surplus brought about by marginal-cost pricing may be turned over to general funds, or to some cherished nonhighway purpose. In the happy event that marginal costs equal average costs the problem vanishes.

Hotelling's Proposition. —Reasoning from the condition of decreasing costs, Hotelling (2) advanced the following thesis:

> ...that all taxes on commodities, including sales taxes, are more objectionable than taxes upon incomes, inheritances, and the site value of land; and that the latter taxes might well be applied to cover the fixed costs of electric power plants, waterworks, railroads, and other industries in which the fixed costs are large, so as to reduce to the level of marginal cost the prices charged for the services and products of these industries.

Hotelling's proof rests on the contention that a commodity tax (e.g., a gasoline tax), by increasing the price and thus reducing the demand, causes both consumers' surplus and producers' surplus to diminish. He demonstrates by diagram that the net sum of benefits under the conditions of a commodity tax will be less than that under the conditions of no commodity tax by an amount proportional to the square of the tax rate. His thesis is stated in more general terms as follows:

> If government revenue is produced by any system of excise taxes, there exists a possible distribution of personal levies among the individuals of the community such that the abolition of the excise taxes and their replacement by these levies will yield the same revenue while leaving each person in a state more satisfactory to himself than before.

It is odd that advocates of substantial public or nonuser participation in highway tax support have not seized upon the Hotelling article as justifying a truly prodigious nonuser share. Perhaps the thought that railroads and other utility enterprises would partake in like manner has deterred them.

Criticisms of Marginal-Cost Pricing.—Hotelling's proposition has been criticized both within and outside the fraternity of welfare economists. Those who are inclined to look coldly on the tenets of this group have attacked on two flanks: First, by assaulting the very fundaments on which the structure of welfare economics is erected; and second, by chipping away at the structure, stressing the difficulties and uncertainties of applying marginal-cost pricing to public utilities and government services, or even to modern business firms. Welfare economists have departed from Hotelling's thesis by reinterpreting the costs of alleged decreasing-cost industries—highways in particular—in such wise that marginal costs exceed or at least equal average costs, as revised.

Little, in a 1951 paper (3), held that the validity of Hotelling's thesis depends on the condition that the supply of labor is not a variable, and concluded as follows:

> If any general conclusion can be risked, it is simply that the best taxes are those on goods for which the demand is least elastic. The same holds true for subsidies. Income tax, which is a subsidy on leisure, is not exceptional. Only in so far as the demand for leisure is highly inelastic is it a good tax. The purely theoretical "case against indirect taxation" is an illusion.

Little's most telling strictures against welfare economics are found in his treatise, "A Critique of Welfare Economics" (4), much of which is devoted to establishing that modern welfare economics, as well as the earlier utilitarian economics, is based on value judgments and is thus prescriptive rather than descriptive in intent. He then proceeds to analyze and restate its basic propositions, which under his hand are shown to be of much less significance and certainty than they appeared to be as originally stated. Directly to the current purpose is Little's comment on marginal-cost pricing in his conclusion (p. 278):

> In particular, we found that the theorem that output ought to be adjusted until price equals marginal cost is extremely shaky, and we did not feel justified in taking much notice of it except in a few special cases. This theorem is the most important and the most controversial conclusion of welfare theory. It lies behind many of the widely accepted practical implications of economic theory. It is highly controversial because it is the only one of the 'optimum' conditions which also has serious political implications. The fact that I cannot bring myself to believe that the distinction between average and marginal cost is, more than very seldom, of the slightest importance to the welfare of society, has led me to the view that this branch of economics—pure static welfare theory—is, or rather should be, of little or no political import.

And again (4, p. 279):

> The commonsense argument that if the market value of one thing is twice that of another, then it is usually worth producing if it does not cost more than twice as much—ambiguous though it is—is probably just as valuable, and is certainly less misleading than such conclusions as 'price ought to equal marginal cost'.

Samuelson (5) devoted a chapter to an exposition of welfare economics. If anything, he is even more genial in his approach than Little, although he is equally insistent that the ethical content of welfare economics be recognized and acknowledged by its practitioners. In his conclusion he emphasizes two points: First, that in the real world adjustments must be made to compensate for the fact that a number of the optimum conditions essential to the application of economic welfare principles will not be realized; and second, that "...the introduction of dynamic conditions into our analysis necessitates a considerable change in the statement of optimal conditions." Of marginal-cost pricing he states:

> Thus, in a world where almost all industries are producing at marginal social cost less than price (either because of monopoly or external economies) it would not be desirable for the rest to produce up to the point where marginal cost equals price.[2]

Coase (7) discussed the views of Hotelling and similar views advanced by Lerner (8), Meade and Fleming (9), and others. Although admitting the theoretical advantages of marginal-cost pricing, even under conditions of decreasing costs, he adds: "But for the same reason it can be argued that the consumer should pay the total cost of the product. A consumer does not only have to decide whether to consume additional units of a product; he has also to decide whether it is worth his while to consume the product at all rather than spend his money in some other direction. This can be discovered if the consumer is asked to pay an amount equal to the total costs of supplying him; that is, an amount equal to the total value of the factors used in providing him with the product." Elsewhere he says: "We thus arrive at the familiar but important conclusion that the amount paid for a product should be equal to its cost." Coase also objects to the fortuitous redistribution of national income that would occur as a result of subsidizing the customers of decreasing-cost industries at the expense of the customers of increasing-cost industries.

To the dilemma he describes Coase finds a solution in multi-part pricing, "... well known to students of public utilities...," in which the consumer is made to pay the total cost of providing the product or service by a system of one or more charges additional to, and applied differently from, the basic charge subject to marginal-cost pricing. It is evident that something like this has occurred in the pricing of highway services, where motor-fuel taxes, the basic charge for use, are supplemented by weight-graduated registration fees at the State level and by manufacturers' excise taxes at the Federal level. Additional use charges are (a) the Federal taxes on tires, tubes, and rubber, (b) State mileage or weight taxes, and (c) toll charges. It can hardly be said, however, that the use charges, or any of them, are, by design, pitched at the level of marginal costs of highway provision.

The multi-part pricing position was taken by Brownlee and Heller (10), who stated:

> The problem contains elements of the well-known difficulty of a decreasing cost industry where, if prices were set equal to marginal costs, total receipts would be less than total costs. If prices were set equal to average costs, too little of the service would be used. In such cases charges for the privilege of using the system and prices equal to marginal costs have been considered

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[2] Samuelson's gentle but skeptical appraisal is further evidenced by his remark, in an appreciation of Hotelling's work (6), "Suffice it to say that Hotelling's theorems can be defended from all criticisms, and form the springboard for an attack on the more difficult problem of what is the best compromise when all price and marginal costs cannot be equated for feasibility reasons."

> the desirable solution. However, in the case of highways, what constitutes the marginal costs of any service is far from settled.

It should be recorded that Brownlee in a later paper (11) states, "One will contend that, for the most part, highway services are such that if they were priced and if costs were computed appropriately, one would be supplying his 'needs' when one produced that amount such that the price—the amount charged for a passage by a particular vehicle—equals the cost resulting from that passage."

Numerous economists have spoken irreverently of the rule, as Lerner named it, of marginal-cost pricing. Radomysler (12) attacks the basic tenets of Lerner's "Economics of Control" (8) on the ground that they are not abstractions from reality, but abstractions from unreality. For example, he says: "Propositions like these, it is usually believed, are only part of the truth; there are in reality, it is usually argued, many disturbing factors. This qualification, however, does not make these propositions any more true than they were before; for what is wrong with statements like these is that they contain no truth at all."

Gordon (13) proceeds, in a sense, to document this charge. His article is primarily addressed, not to government enterprises and decreasing-cost industries, but to marginal-cost pricing as applied to price and output decisions in private industry. He considers and deals with four "essential characteristics" of marginal-price theory, of which only two need be discussed here. The first is that "...business men seek always to maximize profits...." He points out that business men are often guided by non-pecuniary and semi-pecuniary motives as well as by the criterion of maximum profits. The necessity for strategy in dealing with competing firms, with organized labor, and with those from whom capital is to be got, continually dilutes and deflects the pure profit motive, as do the personal traits and limitations of the executive and the pervasive urge for liquidity and security. "These conditions suggest that many business men are likely ... to substitute the principle of satisfactory profits for that of profits maximization. These considerations also suggest ... that business men may seek to use average total rather than marginal cost as a guide in pricing in order to achieve satisfactory profits."

A second essential principle of welfare economics is stated by Gordon (13) as follows: "Profits are maximized in a limited number of directions and it is sufficient in many cases to consider adjustment in only one direction (output)." He points out that business decisions depend on a wide variety of interrelated variables, and battles vigorously against the practice (and implied belief) of economists in picturing demand, cost, price, etc., as single-valued continuous functions of output (the familiar geometric representation illustrated in Figs. 1, 2, and 3). As a particularly disturbing variable he mentions selling costs as distinguished from production costs. One immediately envisions the raucous-voiced washing-machine salesman and the not-so-hidden body of the girl demonstrating an "improved" home permanent—for a million dollars spent on high-pressure advertising can completely alter the cost-price-demand-output relationships of a given product.

These thoughts bring one at once to the central thesis of Galbraith (14) that, through advertising, the demand for goods and services is created along with the goods and services to satisfy it; and that the modern economy, or at least its private sector, is thereby sustained and enabled to function:

> As a society becomes increasingly affluent, wants are increasingly created by the process by which they are satisfied ........ If production is to increase, the wants must be effectively contrived. In the absence of the contrivance the increase would not occur. This is not true of all goods, but that it is true of a substantial part is sufficient. It means that since the demand for this part would not exist, were it not contrived, its utility or urgency, ex contrivance, is zero. If we regard this production as marginal, we may say that the marginal utility of present aggregate output, ex advertising and salesmanship, is zero.

There is, of course, no shortage of economists to defend the orthodox position in pricing theory, and to insist that, with the sophisticated methods of analysis now available, the propositions of welfare economics can be extended to account for the numerous variables that tend to invalidate the simpler theorems. The criticisms cited and discussed in the foregoing do suggest that (a) the structure of welfare pricing theory is not impregnable but rather a bit shaky; (b) the engineer or public official with planning responsibilities is not obligated, under either equity or theoretical considerations, to accept out of hand a taxing or toll scheme based on marginal-cost pricing; (c) in any situation where a marginal-cost pricing scheme is urged as a substitute for existing financing based on the recovery of public outlays, the burden of proof rests on those proposing the substitution; and (d) all such proposals should be examined and tested closely for their social and popular acceptability, for their soundness as elements of the structure of public finance, for the consistency of their objectives with observed trends in the growth and development of the affected area, and for the conformity of those objectives with long-range regional plans tested by the same standards. In short, the criteria of enlightened public policy do not appear to depend very heavily on marginal-cost pricing.

## Mohring's Formulations

Because of its simplicity and directness Mohring's demonstration (15, p. 70ff) will serve well to introduce the principle of congestion-toll pricing. It starts with the concept that the average speed of a vehicle in traffic is a continuous, single-valued function of the volume, as exemplified by the lower curve of Figure 5 of the "Highway Capacity Manual" (16, p. 31), which expresses the relation of average speed and volume on main highways as a line fitting the following equation:

$$\text{Average speed} = 48 \text{ mph} - 0.009 \times \text{vehicles/hour}$$

Here time is taken as the element of cost, and Mohring illustrates the marginal trip-time cost by taking the case of a 48-mi trip and finding the sum of all trip times at traffic volumes of 700 and 699 vph and taking the difference. With trip time equal to distance divided by average speed the calculation is $(N + 1) \frac{48}{48 - 0.009\,(N + 1)} - N \frac{48}{48 - 0.009\,(N)} = (700) \frac{48}{41.700} - (699) \frac{48}{41.709} = 805.7560 - 804.4302 = 1.3258$ hr $= 79.55$ min.

This, in terms of time, is the cost of adding one more vehicle to the traffic stream, as distinguished from the average time cost or travel time, which is 805.756/700 = 1.15108 hr, or 69.06 min. The difference, 10.49 min, is the additional time cost imposed on the other 699 vehicles by the 700th, or marginal vehicle, because it will consume 69.06 min on its own trip.

Figure 4 illustrates the application of marginal-cost theory to this situation. The average and incremental or marginal time-cost curves are plotted to scale from the example previously discussed. The demand-function curve is imagined. The significance of the diagram may be explained in Mohring's words:

> If no tolls were charged, D′ trips per hour would take place. At this level, some driver would just be willing to make a trip if it cost him only the travel time associated with D′ trips per hour. At any level of traffic above D, however, some drivers would be making trips with net values to them of less than the additional costs these trips impose on the remaining drivers. Only at an hourly traffic volume equal to or less than D would each driver place a net value on his trip equal to or greater than the total costs it imposes on other drivers. Only at D, then, would total benefits (the area under the incremental travel time cost function) be maximized.
>
> At this optimum traffic level, the incremental cost and demand functions intersect each other. This level of traffic would develop only if the total cost of a trip is DB. However, if D trips are taken, the travel time cost of a trip is only DA. If only D trips are to be made, an additional amount equal to AB must be charged each driver.

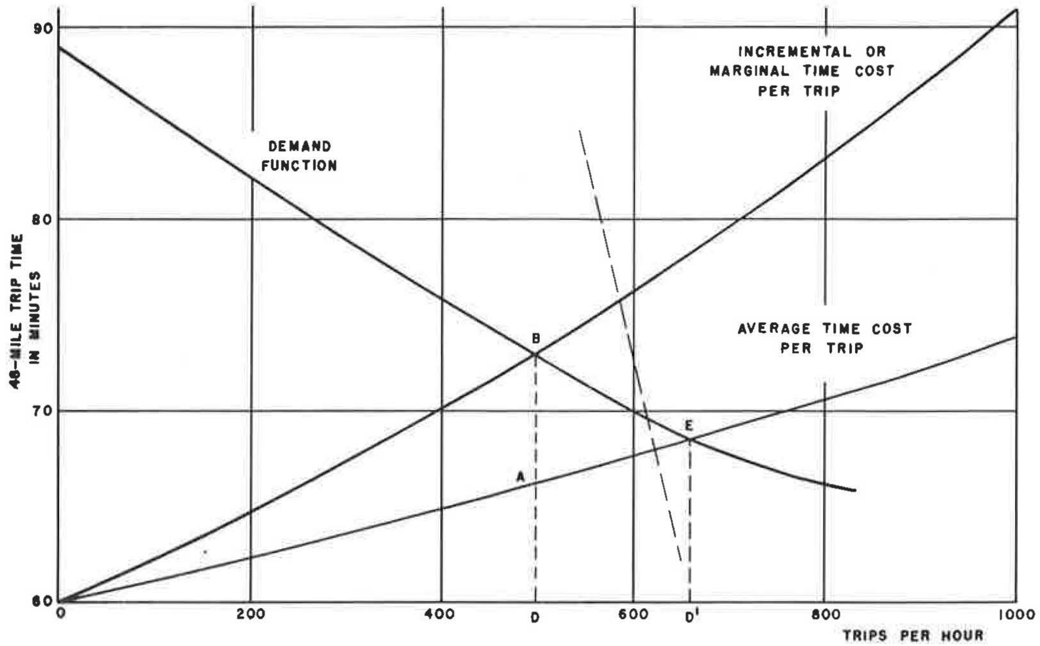


Figure 4. Illustration of average and marginal trip time costs.

Comments on the Congestion-Toll Concepts. —Although Mohring and others have carried the development much further, introducing costs of highway provision as well as other "social" costs into the equations, it is well to pause and examine this elementary formulation, as it underlies all of the more advanced formulations. It presents, ostensibly at least, a simple case of marginal-cost pricing. Because marginal costs exceed average costs, time-delay or congestion costs offer the opportunity of converting the decreasing-cost situation prevailing in public outlays for the provision of highways into a situation of increasing costs.

There is, however, a quirk in this formulation to which the lay observer, particularly one who regards himself as a road user, reacts at once. The motorists are to be charged for the time delays they cause each other. It seems adding insult to injury first to recognize that time delay is a cost to him, and then to say that he must pay, in order to maximize his own benefits, a tax that will cause the cost to leap from the average to the marginal point. This is an unfair attribution, inasmuch as Mohring states (15, p. 79): "Such a tax would, of course, also provide funds to cover the capital costs of the highway." Indeed, he seems to regard the congestion-cost principle primarily as providing a rationale for the existence of user taxes rather than as the occasion for increasing their magnitude.

Another glance at the example previously given may prove rewarding. The total time delay caused to the other 699 vehicles by the presence of the 700th is $10\frac{1}{2}$ min; but the time delay paid for is $10\frac{1}{2} \times 700$, or 7,350 min, inasmuch as each user is taxed for the delay caused by the single unidentifiable marginal vehicle. This seems odd, but it is consistent with marginal-cost pricing, which sets the unit price at the cost ($10\frac{1}{2}$ min plus the actual travel time of 69.06 min) of producing one additional unit.

To put it another way, the removal of the 700th vehicle would reduce the travel time for the 48-mi trip from 69.0648 min to 69.0498 min, a reduction of 0.0150 min (or 0.90 sec) in the travel time of each vehicle making the 48-mi trip. At the AASHO "Red Book" (17) rate of $1.55 per hour or $0.0258 per min for the value of time, the toll charge of 10.49 min amounts to about $0.27. This seems a high price to pay for

so small a savings in travel time. Again this is unfair to the author, for the toll is not proposed as a charge for the time savings but as (a) a toll for the trip itself, (b) a means of rationing and thereby reducing travel, and (c) a source of funds for financing the highway.

But still this seems a rather strange way to handle time savings. Engineers are wont to think in terms of the rather extraordinary savings in travel time brought about by road improvements, and to stake their financial plans on the willingness of users to pay money in taxes or tolls for the time saved. To invoke what appears to be a penalty charge on congestion is likely to impress them as a negative approach.

In concentrating on the desirability of reducing travel time and other vehicular or so-called social costs, those urging congestion pricing have tended to neglect the prime objective of a highway, and indeed to neglect the product. The product, as Figure 4 will remind one, is trips, vehicles per hour, or, in the broadest sense, vehicle-miles. As a reasonable social objective one may perhaps advance that of maximizing the number of trips, the number of units of product that the road may deliver within a given time. It is shown in the "Highway Capacity Manual" (16, p. 38) that the practical capacities of highways are reached at average speeds well below the desired speeds of motorists. It is therefore necessary for the highway planner, the design engineer, and the traffic engineer to arrive at compromises between the ideal of swift, unimpeded travel and the ideal of the efficiency of a road in delivering vehicles per hour, per day, or per year.

Some quotes from the "Highway Capacity Manual" (16) may clarify this point. On page 45 it is stated:

> On most main rural highways, operating conditions are considered satisfactory for the average driver when the operating speed is 45 to 50 miles per hour during all but a few of the peak volume periods in a year.

The manual goes on to state that under these conditions about 70 percent of the drivers will experience some effect of congestion; and cites the exception of toll roads, other high-type rural facilities, and regions in which congestion is rarely experienced, where "... drivers might consider a highway unreasonably congested when those who so desire could not average 50 to 55 miles per hour. . . . " The statement is then made (p. 46):

> On urban facilities with uninterrupted flow, an operating speed of 35 to 40 miles per hour, resulting in an average speed for all traffic of 30 to 35 miles per hour, is considered reasonable.

A two-lane road, under ideal conditions, will accommodate 900 passenger cars per hour at operating speeds of 45 to 50 mph; but, "The corresponding figure for an operating speed of 50 to 55 miles per hour is 600 passenger cars per hour." Thus a gain of 5 mph in operating speed is accompanied by a one-third reduction in the maximum practical capacity of a two-lane road. On multilane highways capacities are greater, but the same principle holds (p. 47):

> The maximum practical capacity of multilane freeways in urban areas, when access and egress facilities are not a factor, is 1,500 passenger cars per lane per hour in the direction of the heavier flow. At this volume, drivers who so desire can safely maintain an overall speed of 35 to 40 miles per hour, although the average speed of all vehicles will be 30 to 35 miles per hour. Also, exceptionally high volumes that occur frequently for short periods can be handled without complete congestion.

Thus, the practical capacity of a road can be realized only at a sacrifice of average speeds, an increase of average trip times. Since publication of the "Highway Capacity Manual" in 1950, progress in vehicular and highway design has tended to increase both lane capacities and the average speeds at which they can be attained; but the principles of highway capacity remain the same.

In a static situation (no road improvement in prospect) the highway official tends to optimize on the basis of maximum practical capacity, which maximizes the output of vehicles per hour at an acceptable level of congestion. In achieving this end the official recognizes that during offpeak hours average speeds will rise and trip times will be reduced; that there will be brief periods of high congestion when the word "tolerable" must be substituted for "acceptable;" that semioccasionally, due to weather, accident, or some other contingency, there will be a real traffic jam; and that he is accepting a calculable level of accident incidence.

In planning and designing a highway construction program, the highway official's objective is to provide equal or greater capacity at higher speeds; but he is again mindful of the necessity to compromise by allowing for maximum capacity consistent with an acceptable level of congestion during peak periods. This concept is built into the principles of highway design; an example is the 30th highest hour proviso.

Are these rules of engineering conduct exemplified in Figure 4? Does the point of intersection of marginal time costs with demand represent the compromise between capacity potential and desired speeds described in the quoted excerpts from the "Highway Capacity Manual?" The answer seems to be that, since the functional relation between capacity and speed was not utilized in the diagram or in the underlying mathematics, it would be only a coincidence if the two points were identical. If they are, then the diagram exemplifies present conditions and practices, except for the suggestion of a toll charge to protect the road from exceeding its practical capacity.

If the points are not identical, and the output OD is below the practical capacity of the road, one has the problem of those potential users whose presence would swell the traffic to practical capacity, but whose valuation of the trip is less than that represented by line DB. Most of these would-be users would be found among those less able to meet the stipulated expense. Without grieving unduly over their plight, and disregarding for the moment the fact that Figure 4 deals with time costs only and not with costs of highway provision, one may pose the question whether equity might not be better served, and indeed a truer maximization of benefits achieved, by setting the price of admission at average highway costs, rather than including a surcharge based on the marginal costs of congestion. (In nontechnical language, it will be hard to convince the layman that a poor man's car should be ruled off the road when he can pay the average costs but cannot afford to pay the marginal congestion costs.) This leads to the further question of whether this model, and the more advanced ones that follow, are not incomplete, in that the demand function, taken alone, fails to account for the social utility of traffic service up to the point of practical capacity.

If the shape of the traffic demand function is greatly different from that portrayed in Figure 4, numerical relations will be altered without disturbance of the theory. The almost vertical dash line on Figure 4 is not Mohring's, but was drawn to suggest the condition of a quite inelastic demand in the region where it intersects the marginal and average cost curves. Under these circumstances very little reduction in traffic volume would be brought about by the surcharge, and the chief motivation for setting the price at marginal congestion costs would be to produce a surplus for use in some desired nonhighway enterprise (assuming highway costs are accounted for).

## Pigou's Two-Road Problem

A problem or illustration by Pigou (18) has become a classic, indeed a sort of basing point for the application of marginal-cost theory to highway pricing. A demonstration of the Pigou two-road problem is given in a 1956 treatise by Beckman, McGuire, and Winston (19, pp. 83-87). As stated by Pigou, it is the case of two roads between two points, one of them broad enough to carry all the traffic that may wish to use it, but of poor quality; the other a much better road but narrow and of limited capacity. The total flow between the two points is assumed fixed. In the absence of a toll an equilibrium between the traffic on two roads is established at the point where the average costs to the users are equal. It is demonstrated that this equilibrium point is not the point of minimal total costs because of the social costs imposed on all users of the better road by marginal users. Beckman's proof is the more general in that it does not assume the inferior road to have indefinitely great capacity.

## Formulations Involving Capital Costs

Until quite recently studies of the efficiency of roads and road networks and of "efficiency" or congestion tolls have been directed toward optimizing the use of the existing road network, and have been concerned little or not at all with the problem of relating congestion-based charges to the cost of providing a continuously expanding road network. The early theorem of Pigou (18) and the more recent work of Beckman, McGuire, and Winston (19) are cases in point. The very recent work of Mohring and Harwitz at Northwestern University (15), of Mohring at the University of Minnesota (20), and of Strotz at Northwestern (21) includes capital highway costs as a term in the equation of net benefits to be maximized, thus producing a marked advance over those treatments assuming a fixed highway plant.

Mohring's One-Road Fixed-Demand Theorem. —Mohring's main contention, implemented by a series of theorems using successively less restrictive assumptions, is that, in the absence of noncompetitive elements:

> Employment of two quite simple operating rules would lead to both a Pareto-optimal utilization of an existing (perhaps non optimum) transportation network and, ultimately, a long-run optimum network. These rules are: (a) Establish short-run marginal cost prices for the use of each link in the existing network; and (b) alter the size of each link to the point where toll revenues equal the costs to the authority of providing that link ....[3]

His first and most simple example is that of a single road between two cities. The rate at which trips are taken depends only on the private cost of a trip, hourly, daily, and seasonal variations being ignored. Private trip cost has two components—whatever toll, T, is charged, and the value of the time required for a trip. Other trip costs are ignored, and the unit value of time, v, is assumed to be the same for all travelers. Travel time per trip depends on N, the number of trips per hour and the quality of the road as indicated by its capital value, K.

If f(n) is defined as the demand function (i.e., the demand price associated with an output of n trips per hour), t(N, K) is defined as the trip time associated with N trips per hour, and r is the rate of interest associated with highway investments, then the equation for the net social benefit of using this highway can be written as

$$B = \int_0^N f(n)dn - Nvt(N, K) - rK \tag{1}$$

The optimum toll is obtained by differentiating this equation with respect to N, or

$$\frac{\partial B}{\partial N} = f(N) - vt(N, K) - Nv\frac{\partial t}{\partial N} = 0 \tag{2}$$

By definition f(N) is the demand price associated with N trips. If this expression is equated to the private cost of a trip, so that $f(N) = T + vt(N, K)$, then substitution in Eq. 2 gives:

$$T = Nv\frac{\partial t}{\partial N} \tag{3}$$

The right-hand expression, giving the value of the optimum toll, can be shown, as in the case of the fixed-plant solution, to be equal to the difference between the average and the marginal time costs of a trip.

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[3]Strotz (21, p. 4) defines the Pareto-optimal situation as follows: "By a Pareto optimum is here meant a state such that no change in the decision variables under public consideration could make any individual better off without making someone else worse off."

The optimum capital value for the highway is obtained by differentiating B in Eq. 2 with respect to K and equating to zero, giving

$$-Nv \frac{\partial t}{\partial K} = r \qquad (4)$$

To quote Mohring (20, p. 6): "In words, the capital value of the highway should be altered to the point where the congestion cost saving per time period resulting from an increment in capital value just equals the capital charge on that increment."

The final step in the demonstration is to show, by the use of homogeneous functions that (a) if providing the road entails constant returns to scale (i.e., simultaneous increases of the same percentage in traffic and capital value would leave trip time cost unchanged) the total toll collections equal the capital charges; (b) if providing the road entails increasing returns to scale (less than proportional costs for a given increase in traffic) toll collections will fall short of capital costs; and (c) there will be a surplus if providing the road entails decreasing returns to scale.

Steps in Generalizing the Theorem. —The second step in the demonstration is to move from the one-road, fixed-demand case to the one-road, variable-demand case, taking account, in particular, of the hourly variation of traffic volume. This is accomplished by expanding the nomenclature so that the significant variables are expressed in terms of the time period, i, and the equation of net benefits involves the summation of benefit and congestion cost terms from i = 1 to i = m. The result is a generalization of the proposition to cover the more complex condition. The analysis then moves to the two-road and two-mode cases. In the two-road case, in which the sum of traffic on the two roads is assumed constant, the object is to determine the optimum difference in tolls between the two roads; and it found that the difference in tolls should be such that the difference in time costs by roads A and B to the individual who, by reason of the toll differential and his own valuation of time, is indifferent between the two, should equal the difference between the costs an additional trip on roads A and B would respectively impose on the remaining A and B drivers. It is further found, under the conditions of constant return to scale, that the difference in optimum interest costs per trip "... precisely equals the optimum difference in the tolls per trip on these roads. Thus, if the highway authority levied 'equitable' tolls—i.e., if it charged each driver on each road the interest costs incurred in his behalf ... —it would not only just cover the costs of the two roads but would also guarantee a cost minimizing allocation of traffic between them" (20, p. 14).

The two-mode case, dealing with the problem of the toll differential between two modes of travel, such as auto and bus, occurring on the same highway, is essentially the same. There the demonstration shows that the difference in bus and auto tolls should equal the difference between the costs an additional trip by auto would impose on the remaining travelers and the costs an additional trip by bus would impose on them.

Further Steps in Mohring's Analysis. —Under "The Costs of Urban Transportation" Mohring (20, pp. 17-23) develops functions and values for average and marginal operating, time, and accident costs, as functions of the volume-capacity ratio. A striking feature is the facility with which data from traffic and other highway engineering research are adapted to an economic analysis. The author's purpose is to illustrate rather than to prescribe and he freely acknowledges instances where he makes bold assumptions or incurs the liability of bias. It is not unfair, however, to cite points in the analysis where, if he had taken a different turn in the road, he would have arrived at more moderate results.

Mohring develops approximations of the average unit value of time from a refinement of the trade-off method, which assumes that a motorist who travels, or desires to travel at, say, 70 mph values time at a rate such as to compensate him for the extra cost of driving at 70 rather than at a lower rate.[4] For this purpose he derives from curves shown in the AASHO "Red Book" (17, pp. 100-126) equations relating gasoline consumption, oil

[4] Mathematically it is a question of minimizing costs. If C = costs per mile, S = speed in miles per hour, v = value of time in dollars per hour, and other costs are represented by a function of speed, f(S), then $C = v/S + f(S)$. Differentiating and equating to zero, $dC/dS = -vS^2 + f'(S) = 0$; $v = S^2 f'(S)$.

consumption, and tire wear to desired speed, and solves for the value of time by the trade-off method. The combined effect is to produce travel-time values varying from -\$0.02 per hour at a desired speed of 20 mph to \$0.62 per hour at 40, \$7.38 per hour at 60, and \$67.82 per hour at 70 mph.

The extraordinary upswing of these values at high speeds is explained by the parabolic equation for gasoline consumption, miles per gallon = $13.2 + 0.40S - 0.0076S^2$ (S being the speed) which gives a value of 4.0 miles per gallon for an automobile at 70 mph. This is much below values encountered when measurements have been made, and calls to mind the danger of extrapolating values from parabolic curves in the vicinity of their reach toward the infinite.

Haikalis (23) uses the variation of operating costs with speed to develop, by the trade-off method, unit values of time varying from zero or a slight negative value at 20 mph to \$1.86 at 60 mph. A refinement of his procedure, produced by smoothing slightly the operating cost values, passing a parabola through them, and differentiating to obtain the value of v, yielded values varying from a slight negative at 20 to \$0.54 at 40, \$2.57 at 60, and \$4.44 at 70 mph. This parabola has no greater claim to validity than Mohring's, but at least the extrapolation does not run wild at 70 mph.

Using a reference to the "Highway Capacity Manual" (16, p. 32) indicating that "... desired speeds on high quality, straight level rural highways are approximately normally distributed with mean and standard deviation of 48.5 and 8 miles per hour respectively...," Mohring integrates his time-value differential equation, and obtains a mean value of approximately \$2.80 per hour. This figure is by no means out of range of recent efforts to estimate the mean of values that motorists place on time savings; but it is clear that this mean, as computed, is heavily weighted by the very high values of high speeds produced by the parabola previously discussed. The value of \$2.80 is cited as indicative that the \$1.55 per hour value recommended in the AASHO "Red Book" is too low. Although there is no reason to accept the AASHO figure as sacred, the Haikalis values indicate that relatively low figures for the unit value of time may not be amiss.

In the absence of a body of evidence to the contrary, Mohring accepts indications in the AASHO "Red Book" of a counterbalancing effect of traffic volume and speed on operating costs under rural operating conditions. In the application to urban arterials, however, he invokes the findings of Haikalis and Joseph (24, p. 55), to the effect that "... both vehicle and accident costs for a trip segment were found to be negatively related to the average speed for that segment..." (20, p. 27). The Chicago Area Transportation Study function for accident costs shows them to vary from \$0.0675 per vehicle-mile at 5 mph to \$0.0180 at 20, \$0.0055 at 30, and \$0.0015 at 60 mph.

In the analysis Mohring, by matching the accident-cost, speed values with average speeds at different values of the volume-capacity ratio for arterial streets, obtains a steep variation of accident costs with increased percentage of capacity. There is grave doubt whether this is a legitimate procedure. Of this curve Haikalis (23, pp. 10-12) says in part, "Streets with low average speeds have high accident rates, and faster arterials and expressways have better safety records. A range of typical route segments was examined.... Accident rates were converted to costs based on the average cost per accident previously described." It is quite evident that this curve was developed from successive sets of accident cost data from ordinary streets, arterial streets, and expressways, and that the indicated speed variation is representative of average speeds on these three classes of highway, each of them designed for a different speed level.

In an earlier CATS report Hoch (25) goes somewhat more thoroughly into the implications of the data on which the Haikalis accident cost vs speed curve is based. One of Hoch's conclusions is as follows (25, p. 2):

> 3. There is some evidence that accident rates increase with traffic volume. Thus, if traffic volume on a street doubles, the number of accidents will more than double. This implies that, in the absence of expressway construction, average accident costs will increase over time.

The text discussion dealing with this relationship is rather less positive:

> In examining the scatter diagrams relating volume and accidents, there was some evidence that rates increased as volume increased. However, the evidence was not too strong. About half the streets examined appeared to have increasing rates with volume, while the other half appeared to have stable rates. Thus, Figure 3, page 25, plots the data for Cicero Avenue; accidents here appear to rise more than proportionately with volume. However, in Figure 4, page 26, for Ashland Avenue, accidents appear to increase proportionately with volume. (25, p. 24)

An increase of accidents at a rate proportional to traffic volume means that the rate per vehicle-mile is constant as the volume increases and hence constant at all average speeds. The most reasonable inference to be drawn is that, if adequate data were available, a separate and different curve of accident costs per vehicle-mile vs traffic volume or volume-capacity ratio could be drawn for each class of road and street—expressways, arterials, minor streets, 2-lane rural, etc.—and that only the average values for each class would become points on a curve such as that presented by Haikalis.

The foregoing suggests that if the calculations of congestion tolls were made with the greatest of care, the results would not be so frightening as they often are. Mohring's analysis results in a schedule of optimum tolls for arterial streets based on marginal operating, accident, and time costs. For a value of time of $1.55 per hour (AASHO rate) the optimum toll varies from $0.007 per mile at a volume-capacity ratio of 0.1 to $0.171 per mile at a volume-capacity ratio of 0.9. At a value of $3.00 per hour the toll schedule varies from $0.012 to $0.288 per mile (22, p. 17).

Mohring (20, pp. 33-52) offers a demonstration of the effects, in reducing daily congestion costs, or variable costs as they are called, of substituting successive increments of freeway capacity for arterial street capacity to carry the existing traffic load in Minneapolis-St. Paul. A rough calculation gave $2.25 million as the cost of freeways that would provide a vehicle-mile capacity equal to 1 percent of existing arterial street capacity. For the first 10 percent freeway increment, the daily savings in variable costs, at a time value of $2.80 per hour, is estimated to be $223,000, or $9,900 per $1,000,000 invested. At a time value of $1.55 the saving is $145,000, or $6,400 per million. At the higher rate the variable cost savings would recover the principal in 101 weekdays. For each successive increment the savings in variable costs is lower, but even at the final increment of going from 80 to 100 percent freeway substitution the savings at the $2.80 rate is $2,000 per $1,000,000 invested, and at the $1.55 rate it is $1,200, for a payout period of 833 days. He concludes: "Finally, even if no value were placed on travel time savings, the operating cost savings provided by this last increment of freeway capacity would aggregate to its capital costs in approximately ten years." (20, p. 52).

All this seems at first glance to be very good news for the freeway advocates—their rosy predictions of freeway benefits doubled and redoubled. The catch is that these striking results are produced by the enormous congestion costs on arterial streets that were built up in the course of the analysis. The implication is that congestion tolls on arterial streets, at the indicated high rates, should be used to finance the freeway system. It may reasonably be suggested that a more modest scale of charges, such as the existing user-tax system, Federal and State, would amortize the freeways at a more normal pace.

The Strotz Formulations.—Strotz (21) covers much the same ground as does Mohring's analysis. However, his treatment is more general, is more difficult for the amateur analyst to follow, and contains some features that appear to advance the theory a few steps further. His first "parable" deals with the one-road fixed-demand case; the second, with the two-road case. The latter differs from Mohring's two-road case (and from its progenitor, the Pigou two-road case) in that it does not assume the combined number of trips on the two roads to be fixed, the solution being therefore

more general and less definitive. The fourth parable takes up the one-road variable-demand case, with the results in the same tenor as those of Mohring.

A distinguishing mark of Strotz's treatment is the fact that each equation defines a sort of cosmos (perhaps "closed circuit" would be a better term) in which the only economic activities are (a) highway expenditures, (b) expenditures on the-production-of-everything-else (defined as bread for simplicity), and (c) the taking of trips on the road. In parables one and two these trips are regarded as pleasure trips; or at least to have no economic attribute other than the cost, d, of making a trip. In the third parable the trips become work trips, and the fact is acknowledged that highways are a link in the chain of production. "The main change.... is that we can no longer regard the total amount of resources available as a fixed quantity. Instead we must consider R.... to depend upon the number of trips made by various individuals." (21, p. 31)

In the fifth parable the possibility is entertained that a rental component should be added to the user toll supporting the highway expenditure to compensate for the contribution to total trip costs by land occupied along any route to the city center. This is a form of argument for a nonuser component in highway taxation, although surely it does not embody all of the reasons that can be adduced for such a component in other contexts.

The results of both these exploits are negative. In the case of the work trips (made for "bread-making" purposes) the optimum toll is the same as for pleasure trips in the first parable; i.e., the amount needed to equate price and marginal trip cost. In the fifth parable it is found that the optimal condition of highway support requires no contribution from special taxes on land. The reason for these results appears to lie in the fact that the process of optimizing utility requires taking partial derivatives and equating them to zero. By this process the mutual relationships that appear so binding in the original equation become unshackled. Although the rental theorem may perhaps be dismissed as trivial in any event, the thought lingers that in the case of the bread-winning work trips a different formulation might cause the mutuality to persist even in the differential form.

## The Walters Article and Comments Thereon

The British economist, Walters (26), developed a model for optimum tolls or taxes based on the marginal social cost approach. The model assumes a road system not subject to change and is therefore less advanced than those of Mohring and Strotz. Among other devices for collecting the charges his calculations require, he suggests an urban gasoline tax of $0.33 per gallon.

During the summer of 1962 three economists at the Bureau of Public Roads were asked by this writer to comment on the Walters article. Because the replies received are germane to the congestion-toll issue, they are reproduced in part here, the deletions being either extraneous or concerned with points peculiar to the Walters article. (Comments were also received from C. M. Grubbs of the University of Colorado, but since Professor Grubbs was a participant in the panel discussion for which this paper was prepared, his comments are not given here.)

Comments by Sidney Goldstein. —

> Professor Walters is analogizing the highway situation to that of the private business where MC and MR must be equal at the best profit position; depending on the extent of competitiveness in the industry, however, MR (marginal revenue) and price will deviate accordingly. The rationale is that if one can arrive at net marginal social cost and set the price at this point one would have the most efficient social arrangement. Implicit in this is the assumption of perfect competition in the private sphere, for it is only in that area that MC = MR = P at its best profit point. Setting price at this marginal social cost would imply that each person using the highway would be paying his full share for his marginal addition to social cost or congestion cost.

This argument falls flat because one can never really obtain true social cost (many amenities are not accounted for and various psychological factors are not included in market price). In addition, only by assuming no future highway construction to relieve congestion is the example valid. But if demand for highways is regarded as a dynamic activity always being upgraded technologically and improved to meet growing demands upon it, then a static approach to taxing congestion on road A-B is merely a logical exercise. It will push traffic to road C or may even remain the same until taxation gets out of all reasonable bounds.

Highway and other public works economists are not in complete agreement on whether only marginal costs or average costs are the proper means of establishing price or whether private industry concepts apply to highways. The author acknowledges this but believes that Meyer, Peck, etc., have erroneous notions about marginal cost pricing.

Professor Walters on page 677 assumes that traffic is homogeneous, all drivers are the same, and all vehicles have the same costs and speed, etc. He agrees that this is wholly unrealistic, but pursues his model in terms of these assumptions as though these were not people with individual preferences but water moving through a conduit pipe.

It is known from experience that costs of vehicles, maintenance, etc., have been no deterrents to motor vehicular use. This is because there are extra-economic factors that are given no consideration, or there are economic factors that cannot be valued in terms of dollars.

The writer is fully in accord with Kanwit's remarks that the administrative proposals for taxing congestion present more problems than they solve and the rural-urban dichotomy as described by Walters is rather extreme.

Walters gives no recognition to the regressive nature of the tax as being most burdensome on those least able to afford it. It would thus aim at keeping lower income individuals out of the cities and city centers, and tend to aggravate an already poor situation.

The proposal for built-in compensations or an equalization mechanism to turn over taxes collected in urban areas (page 697) to those in the local areas is currently already accomplished in a more painless and hidden fashion through the present user taxes. The use of congestion taxes in urban areas might well accentuate the dispersal of communities and industry.

The empirical data presented by Professor Walters were found to be weak reeds, indeed, upon which to hang such an all-embracing proposal.

Walters appears to have given little consideration to the redistributional effects on urban and rural structures that could be put into motion by the congestion tax. If this scheme is effective, the capital loss in building investment could be quite significant. To counter any such tendencies, alternative transportation investments must be considered in order to retain the current centers. Walters does not discuss this aspect, however. Neither is there any discussion of "equity" or a more equitable arrangement for taxation, such as incremental costs associated with different size vehicles, etc., or taxation of real estate and businesses benefitted by highways. In fact, this is dismissed on page 697 with the following statement: "Generally, urban car users will be injured by these arrangements and the reduction in the density of traffic will have various other repercussions on property owners—and on the automobile industry. It would be both difficult and tedious to try, at this state, to trace all the reactions in the various classes of the community."

## Comments by E. L. Kanwit. —

The writer would not presume to attempt to unravel Mr. Walters' econometrics. Basically, I disagree with the attempt to apply the economics of competition to the highway. The public highway which is free and open to all cannot be equated with a monopolistic mode of transportation operated for private profit.

... The current situation can hardly be divided neatly into "urban" and "rural" situations. The extent of variation among "urban areas" (for example, Boston and Oklahoma City); the complete and utter dependence of the suburb on the motor vehicle; the fact that commercial vehicles would immediately pass on higher transportation costs; the essentially regressive character of his tax proposal, are neatly ignored.

Even more important would be the catapult-like effect on existing economic geography should the theoretical economic notions actually be permitted to go into effect. The centrifugal tendencies of residence and employment are already the most dynamic factors in the changing structure of American cities; Walters' proposals would be the coup de grace to the downtown core.

Actually, with some 90 percent of entrants into the Manhattan CBD using public transportation, and more than 80 percent of Chicago's, how much is left to accomplish which high parking, congestion, and urban highway backlog haven't already achieved?

Presumably the purpose underlying the toll suggestions is to maintain and increase concentration of activity at the urban core. I doubt if a more self-defeating proposal—in the long run—could be devised.

The trouble with Walters' logic is the old <u>ceteris paribus</u> bugbear. He assumes that the principal result of raising prices will be to create a more desirable equilibrium in precisely the same context in the situs of activity. To some extent, in the short run, this would be achieved with gross injustice to those whose behavior had been planned on entirely different pricing. In the long run, the partial equilibrium created to the dissatisfaction and annoyance of millions would unchain a series of reactions which would be as revolutionary as those which unrestricted "automobility" has created.

## Comments by John Rapp. —

Essentially, Walters is purporting a theory of equating highway prices with the marginal social cost involved in their existence. The basic intent is to tax congestion. In developing his geographical analysis, he relates private costs to density of traffic. This concept of highway finance, however, fails to be of much usefulness. It does not really construct a supply function which relates the cost of highways themselves to the amount of highway service. Had this been done, the unit cost curve would be likely to decline over a wide range. This renders the analysis useless and illogical. In several places the graphs are improperly labeled, sloppily constructed, and contain misstatements.

The entire analysis implicitly assumes that no new highway construction will take place. Marginal cost pricing, Walters says, is appropriate only for the efficient utilization of existing facilities. A partial solution to congestion, however, is the construction of new highways. In the absence of new construction, congestion would only be relocated. For this reason, serious doubts can be raised concerning the applicability of marginal cost pricing to highways. He even states that the costs of providing highways are irrelevant to the highway tax problem.

Walters completely denies that there should be any attempt to obtain highway payments from the general public and landowners. This

completely contradicts his criterion of efficient resource allocation. It is quite clear at this point that Walters is not acquainted with the real problems of modern highway finance. He proceeds to deny that there is validity in the standard of tax neutrality in highway finance. To deny this is to open the door to total inequity in highway finance.

His mathematical exposition is similar to many econometric treatments of price theory. He adds the element of congestion and implicitly makes the judgment that the reduction of congestion is the sole aim of highway taxation. His final formulas (Eqs. 7 and 10) are incapable of solution—this he admits. Further, there is no way possible to even make a reasonable estimate of the necessary data. Hence, no practical purpose is served—neither is any theoretical validity obtained.

Equity is, apparently, of no concern to Walters. The discrimination between urban and rural tax rates, his disregard for possible adversities resulting from his recommendations, and his disinterest in nonusers all testify to his lack of desiring an equitable solution.

**The Demand Function.**--Walters did, however, make the significant point that it is very difficult to determine the demand function on any road.

That is to say, the data available enable one to identify the cost curve, but the demand curve remains unidentified. The demand parameters are, however, very important for estimating the effects of road improvement as well as for the more menial task of fixing efficiency tolls (26, p. 686).

Mohring (20, pp. 21-27) gets around this difficulty by estimating the marginal cost (or rather, the excess of marginal over average cost) for different values of the volume-capacity ratio. Then, for any street or street network having a volume-capacity ratio of, say, 0.7, 0.8, or 0.9, the corresponding estimated amount is stated as the optimum toll. There seems to be an element of error in this maneuver. Before the congestion toll is imposed the price is equal to the average congestion cost plus the user-tax cost, which may be assumed to be less than the congestion toll based on marginal cost. The demand, then, is fixed by this price and not by the marginal cost. If TC is the user-tax cost, the following expression may be written for the price:

$$P = AC + TC < MC$$

Imposition of a congestion toll would produce a reduction in demand, which would be associated with a new (presumably reduced) value of marginal cost. It would be at best a matter of experimentation, or trial and error, to determine the point where the tax imposed becomes equal to the calculated marginal cost increment. The user might experience some discomfort during this experimental period, but then, so does the guinea pig.

There is a possibility that valid demand functions could be developed from traffic assignment models, which Walters dismisses, perhaps too summarily, with the statement: "Unfortunately there is no way of eliciting the characteristics of the demand curves from the engineers' results." (26, p. 687) Because assignment models customarily contain functions expressing the inverse variation of trip frequency with trip cost, there would seem to be a chance, assuming that data confirm their validity, of conversion to the terms of an economic demand-cost function.

## The Gown and the Salesbook

An interesting contribution to the congestion-toll debate was made in 1959 by a university professor testifying before the Congressional Joint Committee on Washington Metropolitan Problems (27). The testimony in itself was not a significant con-

tribution to congestion-cost theory, although the witness presented exhibits of previous work done by him in this field. It was distinguished by the fact that the professor brought with him, and introduced to the Committee, a salesman for a corporation manufacturing an electronic device by means of which a vehicle passing a point may be identified, its travel within a delimited area thus measured and recorded on a central computer, and the owner billed monthly for the amount of congestion toll due.

The combination of academic expertise with high-pressure salesmanship is not unknown to the American scene, but is always of interest to observe. This episode should at least suggest that economic factors and influences are at work that are not comprehended in the congestion-toll models produced to date.

It is not intended in this paper to consider the various devices that have been developed or suggested for metering the motorist's congestion tax or toll obligation. Their adoption is contingent upon the somewhat doubtful public acceptance of congestion tolls as a substantial factor in road-user taxation. One must, however, be alert for future contingencies. If vehicle propulsion systems become so varied that the motor-fuel tax is no longer a viable instrument for allocating and collecting road-user taxes, mechanical or electronic devices may prove to be the most logical means of metering highway use. This is uncomfortable to contemplate, but it has to be put on the list of things to be considered.

## IMPLICATIONS OF CONGESTION-COST THEORY

For a mathematical model, whether in economics or in any other science, to gain acceptance it must pass three tests: (1) The assumptions on which it is based must be accepted as valid; (2) the mathematics must be impeccable; and (3) inasmuch as every model is an abstraction from real life, and therefore much simpler than actual conditions, the model must embody the essential sources of variation that are encountered in the real situation. The layman would better leave the mathematics severely alone; and he is quite likely to get out of his depth in exploring the basic assumptions. His best approach to the consideration of the applicability of such a formulation is therefore to ask if it does represent real conditions to a respectable degree; for the layman actually exists in real life and may have as much or more experience in the particular aspect of it than the formulator of the model. Caution must be exercised in the criticism, however. One may say that the model covers only static or short-run conditions, only to find that the eager economist is incited by this criticism to fabricate an even more baffling model to cover the long range. The comments given here are made in the spirit of inquiry rather than opposition. The effort is to examine the implications and the import of this system of formulas in the light of actual situations and the necessities of action in the field of highway transportation.

### The Formulations in Relation to Changes over Time

The first reaction of one accustomed to paying user taxes is that these equations call for a form of double taxation, or at least double payment of vehicular costs. The user realizes that he is incurring costs in the form of time delays, strains and discomforts, and perhaps running costs, when he travels in congested traffic. To be asked to pay again for his suffering seems a little too much. It is true that he is being taxed for the delays and discomforts he causes his fellow motorists, but they too are asked to pay. He asks why he should incur these congestion costs twice.

To this objection there are two principal rejoinders. The first is that the object of the tax or toll is to maximize benefits rather than to penalize the motorist. The second is that the marginal cost of congestion, or rather, the difference between marginal and average cost, is a measure of the optimum value of the tax, the proceeds of which will presumably be used either to build and maintain roads or for some general purpose beneficial to all, if not to the users in particular.

These answers are not entirely satisfactory, partly because there is a certain ambivalence among the stated objectives of the advocates of congestion tolls. Mohring

(15, 20) and Strotz (21) throughout their analyses appear to regard the congestion-toll theory as a rationale for the enactment of user taxes and as a guide for the fixing of their magnitude. Their fomulations tend toward the proposition that, under most circumstances, a user tax can be found such that it will both equate to marginal social costs (i.e., congestion costs) and exactly meet highway costs at the same time. Beckman (19, pp. 99-100) in dealing with the two-road problem states: "From the point of view of the community the tolls do not constitute costs but are available again for redistribution or use in road construction and maintenance." Others, however, seem to disregard the relation of congestion tolls to public outlays for highway provision, and look eagerly toward their use as a source of subsidy for other modes of urban transportation, such as rapid transit.

Another difficulty, which has been noted by Mohring (15, p. 80), is that charges pitched to the marginal costs of congestion would tend to be high when the provision of highway service is inadequate and low when it is adequate. Thus, at least in its simplest form, the congestion-toll theory does not seem to provide for the case of a freeway program to eliminate congestion. The dilemma, if it can be so described, can be stated in another form. If the charges are based on existing congestion, the revenues they bring in will dry up (a) if they are successful in diverting motor vehicle traffic to rapid transit, or (b) if an adequate freeway system is built. The more formal and complete treatments of Mohring and Strotz, which include capital outlays in the equations, seem to eliminate this difficulty. One may be skeptical as to whether they truly represent the case of an accelerated program for providing a freeway network.

The issue is confused somewhat by the circumstance that so much of the capital outlay for highways is financed out of current revenues. Thus the users of completed highways are continually supplying the revenues for the building of new ones. This situation, which causes no anguish either to the users, to highway administrators, or to user-tax administrators, is most vexatious to some economists (28, p. 11) who speak of one class of road users "subsidizing" another. If a city or metropolitan area did not have a freeway system and one is now being built out of Federal and State road-user tax revenues, it is quite easy to say that the future freeway users are subsidized by millions of users of other roads, both rural and urban. That the freeway system gives every evidence of solvency in terms of earnings compared with annual cost is no deterrent to the charge.

Mohring's demonstration of potential freeway benefits in the Twin Cities (20, pp. 51-52) is a case in point. They will pay out in a very few years, even if there is a 100 percent substitution of freeways for arterials. But during the building period, surely, because the charges are to be based on congestion costs rather than on anticipated savings, the luckless users of the arterial streets will be paying the bills—"subsidizing" the freeway users of years to come.

The toll-road situation is the one preferred for model making, being viewed as a closed-circuit operation in which the users pay directly for the service received and toll collections are used to retire the debt and maintain and operate the road. Public (as distinguished from revenue) bond issues served by user-tax proceeds are a substitute, but one frowned upon by those more inclined toward economic niceties than toward the actual saving of user-tax monies. Two grounds of objection are: (1) Quite often such bond issues are backed by the full faith and credit of the State and, even when buttressed only by pledged user-tax revenues, they command interest rates much lower than those of toll-supported revenue-bond issues; and (2) During the construction period interest and retirement charges are paid out of the general pool of user-tax funds (i.e., the earnings of other roads), any special financing for "interest during construction" being thus avoided. Even toll facilities are not immune from this evil, if such it be, for today's tolls are continually being used to finance (a) increases in the capacity of the toll road itself by the addition of lanes and other improvements, and (b) extensions of the toll-road or toll-crossing system over which the toll authority has jurisdiction (29, pp. 26-43).

It is customary to avoid these twists and turns of financing by the introduction of an annual-cost term (such as Mohring's rK), to serve as the equivalent of any form of

financing whatever. The uncertainty about the "true" value of the interest rate (values ranging from zero to 20 percent per annum (30) have been cited) is perhaps sufficient to suggest that expressions of theoretical annual cost, although often useful, are an inadequate abstraction from the real life of public investment financing. Indeed, if annual-cost expressions can truly perform the role of substitution, the question of whether to finance a highway program by means of general obligation bonds, toll revenue bonds, or current revenues is of no consequence. But the question is of consequence; decisions about financing enter into the summation of costs and benefits involved in long-range highway programs.

A model that would take adequate account of all the significant variables in highway planning and financing would be very complex, but perhaps not beyond the resources of mathematical economics and automatic data processing. It would need to be a dynamic model, taking account of variations over time, if only to allow for the business of this year's road-user taxes financing highways to be used in subsequent years. Introduction of the time dimension, not used in any of the formulations yet produced, would take account of the growth of traffic and the increase over the years in the extent and capacity of the highway network. The model would also have to deal with the community, business and income effects of the decisions made regarding highway taxation and financing, some of which are discussed later herein. It is possible that such a dynamic model embodying macro- as well as micro-economic effects, would find marginal-cost pricing playing a less prominent role than in the static models now under consideration.

## Urban Highway Costs

The cost of constructing, maintaining, and operating urban highways and streets is one of the principal factors in the economics of congestion tolls. Both Mohring (20) and Strotz (21) have recognized this fact in writing highway cost terms into their equations, although it is questioned whether a single term in an essentially static equation can fully represent the effect of expanding and improving highway networks over time. The question of whether current urban highway and street costs are such as to require special urban user surcharges is therefore pertinent.

An interesting sidelight on this question is cast by Mohring's calculation, previously discussed, of the reductions in motorists' variable costs (operating, accident, and time) that would result from substitution of freeways for arterial streets in the Twin Cities (20, pp. 51-52). The results show, in effect, that, if congestion tolls were imposed at rates sufficient to recapture the cost reductions or benefits derived from the substitution, the freeways could be paid for in less time than it would take to build them. In this there is a suggestion that much lower user tolls or taxes would amortize the investment at a rate more normally related to the useful life of the facility. And this brings up the question of whether present methods of financing major urban improvements approach this desirable norm.

Nationwide Comparisons of Expenditures and Travel. —One of the indictments sometimes brought against present-day urban highway financing is that highway expenditures in urban areas greatly exceed either (a) the user-tax revenues made available for highways in these areas, or (b) the user-tax revenues generated in these areas. To the first of these charges there is some substance because benefit assessments, property tax revenues, and local general funds still supply much of the revenue for local city streets. To the second charge there is little or no foundation. Neither is there any basis to the claim that urban motor vehicle travel is subsidized by rural travel.

Table 1 gives a comparison of expenditures and travel on rural and municipal roads and streets in 1961. The expenditure figures include all funds, Federal, State, and local, applied to highways in that year. Expenditures on all roads and streets were \$10.8 billion, of which \$7.1 billion or 65.1 percent was spent on rural roads and \$3.8 billion or 34.9 percent was spent on municipal highways and streets. In contrast, the estimated travel on rural roads was 398 billion vehicle-miles, 54.0 percent of the total, and that on municipal highways and streets was 340 billion vehicle-

TABLE 1

COMPARISON OF DISTRIBUTION OF 1961 HIGHWAY EXPENDITURES ON RURAL ROADS AND MUNICIPAL ROADS AND STREETS[1], WITH CORRESPONDING DISTRIBUTIONS OF 1961 MOTOR VEHICLE TRAVEL[2]

| Item | Rural | Urban | Total |
|---|---|---|---|
| Expenditures ($ million): | | | |
| Capital outlay | 4,365 | 2,429 | 6,794 |
| Percentage distribution | 64.25 | 35.75 | 100.00 |
| Other expenditures: | | | |
| Maintenance | 1,905 | 842 | 2,747 |
| Highway police and safety | 192 | 159 | 351 |
| Administration and research | 344 | 175 | 519 |
| Interest on highway debt | 253 | 174 | 427 |
| Subtotal | 2,694 | 1,350 | 4,044 |
| Percentage distribution | 66.62 | 33.38 | 100.00 |
| Total expenditures ($ million): | 7,059 | 3,779 | 10,838 |
| Percentage distribution | 65.13 | 34.87 | 100.00 |
| Vehicle-miles of travel (millions) | 397,902 | 339,633 | 737,535 |
| Percent distribution | 53.95 | 46.05 | 100.00 |
| Expenditures (¢ per veh-mi) | 1.77 | 1.11 | 1.47 |

[1]Source: Table HF-2, Department of Commerce release BPR 63-2, January 13, 1963. State expenditures for highway police and safety, administration and research, and interest on highway debt prorated to State and local rural and urban roads in proportion to distribution of capital outlay and maintenance. Federal expenditures for administration and research estimated 60 percent rural and 40 percent urban.
[2]Source: Table VM-1, 1961, "Highway Statistics 1961," p. 25.

miles, or 46.0 percent. In terms of expenditures per vehicle-mile these 1961 totals amount to $0.0177 for rural roads and $0.0111 for municipal highways and streets. It is quite apparent that, if there is a "subsidy," it flows outward from the cities rather than inward from the rural areas.

Evidence of the Section 210 Study. — Table 2 consists of a series of comparisons made with the data on estimated highway needs that were collected as a part of the highway cost allocation study project conducted under the terms of Section 210 of the Highway Revenue Act of 1956. The data are given for all highway systems, including Interstate, other Federal-aid primary, Federal-aid secondary (State and local), other State highways, and other roads and streets. Each system group is divided into rural and urban components. The data are tabulated in terms of the cost, in cents per vehicle-mile, of a 16-year improvement program (1956-1972) based on the highway needs estimates made for all road and street systems as a part of this study. Thus the calculations for all systems are on a uniform basis, although there is an element of unreality in that only the Interstate System has been held to a program that would meet its estimated needs in the period 1956-1972. Maintenance and operation costs have been included in the calculations.

The first column of figures gives the average annual program costs. This form of expressing costs assumes a program financed out of current revenues, which is entirely the case for Federal funds and the prevailing situation for highway expenditures as a whole. The costs per vehicle-mile under the current-revenue program are expressed in terms of predicted 1964 travel, as that is the midyear of the projected 16-year improvement program. In the remaining three columns costs per vehicle-mile are expressed as annual ownership costs as of 1975, at 5 per-

TABLE 2

COSTS, IN CENTS PER VEHICLE-MILE OF TRAVEL, OF A 16-YEAR IMPROVEMENT PROGRAM[1] FOR ALL ROADS AND STREETS, 1956-1972

| Highway System | Method of Cost Calculation | | | |
|---|---|---|---|---|
| | Average Annual Program Costs[2] | Annual Costs in 1975 at 5.0% Interest | Annual Costs in 1975 at 2.5% Interest | Annual Costs in 1975 at 0.0% Interest |
| Interstate: | | | | |
| Rural | 1.69 | 0.89 | 0.60 | 0.38 |
| Urban | 2.00 | 1.05 | 0.65 | 0.34 |
| Total | 1.81 | 0.95 | 0.62 | 0.36 |
| Other Federal-aid primary: | | | | |
| Rural | 1.36 | 1.38 | 1.05 | 0.79 |
| Urban | 1.23 | 1.02 | 0.73 | 0.50 |
| Total | 1.32 | 1.27 | 0.95 | 0.70 |
| Federal-aid secondary, State: | | | | |
| Rural | 1.72 | 2.04 | 1.62 | 1.28 |
| Urban | 1.13 | 0.94 | 0.68 | 0.47 |
| Total | 1.63 | 1.86 | 1.47 | 1.15 |
| Federal-aid secondary, local: | | | | |
| Rural | 2.24 | 2.33 | 1.90 | 1.54 |
| Urban | 0.97 | 0.83 | 0.65 | 0.50 |
| Total | 1.98 | 2.02 | 1.64 | 1.33 |
| Other State highways: | | | | |
| Rural | 2.77 | 3.53 | 2.76 | 2.12 |
| Urban | 1.06 | 1.05 | 0.76 | 0.53 |
| Total | 1.97 | 2.38 | 1.83 | 1.38 |
| Other roads and streets: | | | | |
| Rural | 3.35 | 3.92 | 3.24 | 2.70 |
| Urban | 1.38 | 1.56 | 1.26 | 1.02 |
| Total | 1.97 | 2.30 | 1.88 | 1.54 |
| Summary: | | | | |
| All rural | 1.91 | 1.84 | 1.44 | 1.12 |
| All urban | 1.41 | 1.26 | 0.95 | 0.70 |
| All roads and streets | 1.70 | 1.61 | 1.24 | 0.95 |

[1]Source: Calculations based on estimates of highway needs made as a part of the Highway Cost Allocation (Section 210) Study. Values are for roads and streets in the 48 States and the District of Columbia, exclusive of toll facilities.
[2]Based on predicted 1964 vehicle-miles.

cent, 2.5 percent, and 0.0 percent interest, respectively, the year 1975 being taken as a year when the highway improvements built during the 16-year program of 1956-72 have become fully operative.

Turning first to the current-revenue column it is found that for all roads and streets the program costs of rural roads are \$0.0191 per vehicle-mile and those of urban highways and streets are \$0.0141 per vehicle-mile, indicating something rather different from a subsidy of the urban users by the rural. The greater unit costs of rural roads persist on all systems except the Interstate. There the extraordinary outlays required for right-of-way and structures on urban freeways tip the balance and urban costs are \$0.0200 against \$0.0169 for rural costs.

In calculating annual costs the capital outlays are amortized, at a given rate of interest, over the estimated life of the investment. Inasmuch as right-of-way and structures are long-lived investments, their prominence in the urban program causes alterations in the rural-urban cost relationships. Where the interest rate is high a preponderance of long-lived investments tends to raise the relative cost per vehicle-mile. At a low rate of interest the reverse is true.[5] At 5 percent interest the same general relationships hold between rural and urban costs per vehicle-mile as in the current-revenue calculation. On the Interstate System the ratio of urban to rural costs remains about the same, being 1.18 in both cases. In this calculation the lower cost per vehicle-mile of the higher-order heavy-traffic systems becomes quite evident, except for a few "maverick" cases, all of them low urban costs.

The 2½ percent rate is perhaps more suitable for highway investments because (a) the tax exempt general obligation bonds of the States can be sold at rates of this order (a rate of 3 percent would be more closely representative of State general obligation bonds in the last few years), and (b) the net yield of Federal issues, which are subject to the Federal income tax, is of the same order. At 2½ percent the disparity between rural and urban cost per vehicle-mile on the Interstate System is materially reduced, the comparison here being \$0.0065 against \$0.0060. The calculation for the no-interest condition (amortization only) causes the situation on the Interstate System to reverse. For this calculation the rural costs are \$0.0038 per vehicle-mile and the urban costs \$0.0033.

The fact that the expression of these expenditures in terms of annual costs greatly reduces their magnitude in comparison with the program or current revenue costs is quite evident, particularly on the Interstate System, although the 5 percent rate causes expenditures on some of the lower systems to be higher on an annual cost basis than on the current revenue basis. Because the annual cost calculations without interest can hardly be accepted as ruling, it can be accepted as true that the cost of providing urban Interstate improvements and facilities of like order tends to be somewhat greater per mile of travel on them than the cost of providing rural facilities of the same order. A cost difference of 18 percent, or only 8 percent in the case of the 2.5 percent calculations, does not seem to produce the occasion for imposing extraordinary increased charges on urban users. This is the sort of differential that Federal, State, and local governments seem quite able to take in their stride.

The fact is, of course, that if the cost per mile of segments of a freeway were to be traced from its point of origin in the open country to its point of nearest approach to the central business district, the probable result would be an irregular but definitely upward gradient. In terms of cost per mile the slope would be rather steep. In cost per vehicle-mile the upward trend would be much milder, and in some cases the profile would be level, or the slope would reverse, depending on the extent of large outlays for right-of-way and the variation in traffic volumes. When one considers that it is the suburban resident whose commuting by auto is charged with causing

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[5] An article in the March 1962 issue of "National Tax Journal" contains the following footnote: "Irving Fisher noted long ago (in "The Theory of Interest," Ch. VII) that in societies where rates of interest were high there would be incentives to build wooden bridges rather than steel ones, and in general to substitute short-lived assets for longer-lived ones which serve the same purposes."

intolerable congestion, and whom it is hoped to lure to the rapid-transit cars, one is forced to conclude that these peak-hour commuters are subsidizing themselves.

Highway Expenditures and Earnings in Standard Metropolitan Statistical Areas. — When confronted by figures of this sort, critics of urban freeway and arterial expenditures have responded that the terms "urban" and "municipal" cover a wide range in size of place, and that the urban costs per vehicle-mile are heavily weighted by costs in small places having conditions very like those of the rural areas. It is quite true that the figures for urban places as a whole do include the expenditures of small cities. It is untrue, however, that this produces a large distortion of the costs per vehicle-mile or in any sense misrepresents the relation of urban highway costs to the contributions by urban motor-vehicle users. Tables 3, 4, and 5 compare the 1960 revenues and expenditures for highways of a group of 46 SMSA's (Standard Metropolitan Statistical Areas)[6] with the revenues generated by the vehicles and traffic within the area. The data represent the summarized results of a Bureau of Public Roads study, not yet published, in which the effort was made to obtain data of this sort from at least one urban area in each State. The selection of cities given here provides good geographical coverage as well as a wide range in population.

The data on highway income and expenditures were obtained from reports received by the Bureau of Public Roads in its annual urban highway finance studies (31, pp. 70-83). The vehicle-miles traveled in each SMSA in 1960 were estimated from traffic counts, information from transportation studies, and other available data. User-tax earnings, State, Federal and local, were estimated as follows: (1) Taxes based on motor-vehicle use, such as motor-fuel taxes and the Federal excises on tires, tubes, and rubber were estimated on the basis of average consumption factors applied to the vehicle-mile estimates; (2) Taxes based on ownership, such as State registration fees, were applied to motor vehicles registered in the area in 1960; (3) Tolls paid at crossings within the area were counted in full; (4) Toll-road earnings were estimated on the basis of the vehicle-miles traveled on toll roads within the area; and (5) Payments of the Federal manufacturers' excise tax on trucks, buses, and combinations, were also estimated on the vehicle-mile basis.

Table 3 lists the 1960 income for roads and streets of these 46 Standard Metropolitan Statistical Areas, divided into four population groups. Revenue income items are divided into (1) road-user imposts, Federal, State, and local (including tolls) and (2) other income, including property taxes and assessments and general fund appropriations. It is of interest that in only three SMSA's (Atlantic City, N. J.; Lewiston-Auburn, Me.; Wichita, Kans.) did the local nonuser income exceed the income from road-user imposts. In the smaller places user taxes and tolls provided 76.4 percent of the revenue income; in the places of 250,000 to 500,000 population, 75.4 percent; in the places of 500,000 to 1,000,000 population, and in the places over 1,000,000 population, 73.1 percent. For the entire group the percentage was 73.4. The fact that nearly 28 percent of the highway income of these 46 places came from local nonuser sources does, however, illustrate the persistence of the traditional methods of financing ordinary local roads and streets.

Expenditures in the 46 SMSA's are given in Table 4. Because nearly all of them contain land classed as rural (much of it suburban but some definitely rural and even wild land), capital outlays are divided into rural and urban portions as well as between State-administered highways and local roads and streets. In all four sizes of place the dominance of the State program, which includes Interstate and other Federal-aid projects, is evident. For the entire group of 46 SMSA's expenditures on State projects totaled $686 million out of total capital outlays of $935 million, or 73.4 percent. Maintenance, administration, and operation, including allied functions, such as traffic policing and control, parking, and street lighting, accounted for $476 million and

[6] A Standard Metropolitan Statistical Area, selected by the Census Bureau for convenience of reporting, consists of the counties containing the entire urbanized portion of a metropolitan area. The SMSA includes, of necessity, the rural portions, if any, of its constituent counties.

TABLE 3

ROAD AND STREET INCOME OF 46 SELECTED STANDARD METROPOLITAN STATISTICAL AREAS IN 1960
(In $1,000's)

| Standard Metropolitan Statistical Areas by Population Group | From Imposts on Road Users: State Road-User and Federal Trust Fund Taxes | Local (includes parking fees) | Tolls, State Facilities | Tolls, Local Facilities | Total | Other Revenue Income: Property Taxes and Assess-ments | General Fund Appro-priations | Miscel-laneous | Total | Total Revenue Income | Investment Income and Borrowing | Total Income | Funds Drawn from (+) or Placed in (-) Reserves | Total Funds Available |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Under 250,000: | | | | | | | | | | | | | | |
| Atlantic City, N. J. | 2,385 | 273 | 380 | - | 3,038 | 1 | 3,593 | - | 3,594 | 6,632 | 221 | 6,853 | + 12 | 6,865 |
| Bay City, Mich. | 5,158 | - | - | - | 5,158 | 48 | 449 | 219 | 716 | 5,874 | 555 | 6,429 | - 53 | 6,376 |
| Cedar Rapids, Iowa | 2,833 | 210 | - | - | 3,043 | 2,214 | 22 | 122 | 2,358 | 5,401 | 561 | 5,962 | + 1 | 5,963 |
| Charleston, S. C. | 4,082 | - | - | - | 4,082 | - | 485 | - | 485 | 4,567 | - | 4,567 | + 120 | 4,687 |
| Eugene, Ore. | 12,507 | 276 | - | - | 12,783 | 1,292 | - | 39 | 1,331 | 14,114 | 696 | 14,810 | - 679 | 14,131 |
| Fargo, N. D. | 12,821 | - | - | - | 12,821 | 1,983 | 573 | 133 | 2,689 | 15,510 | 2,186 | 17,696 | - 152 | 17,544 |
| Fitchburg-Leominster, Mass. | 306 | 1,012 | - | - | 1,318 | - | 269 | 198 | 467 | 1,785 | 7 | 1,792 | - | 1,792 |
| Fort Wayne, Ind. | 4,596 | 95 | - | - | 4,691 | 1,079 | 171 | 68 | 1,318 | 6,009 | - | 6,009 | - 165 | 5,844 |
| Great Falls, Mont. | 3,517 | 137 | - | - | 3,654 | 1,627 | - | - | 1,627 | 5,281 | 181 | 5,462 | - 116 | 5,346 |
| Jackson, Miss. | 3,906 | 137 | - | - | 4,043 | 2,761 | 848 | 301 | 3,910 | 7,953 | 2,313 | 10,266 | - 585 | 9,681 |
| Las Vegas, Nev. | 4,367 | 197 | - | - | 4,564 | 635 | 424 | 139 | 1,198 | 5,762 | 460 | 6,222 | - 49 | 6,173 |
| Lewiston-Auburn, Maine | 111 | 134 | 272 | - | 517 | - | 717 | 15 | 732 | 1,249 | 20 | 1,269 | - 9 | 1,260 |
| Lexington, Ky. | 1,606 | 81 | - | - | 1,687 | - | 826 | - | 826 | 2,513 | 188 | 2,701 | + 2 | 2,703 |
| Little Rock-No. Little Rock, Ark. | 19,151 | 188 | - | - | 19,339 | 1,084 | 943 | 157 | 2,184 | 21,523 | - | 21,523 | + 993 | 22,516 |
| Lynchburg, Va. | 2,202 | 260 | - | - | 2,462 | 4 | 412 | 2 | 418 | 2,880 | 788 | 3,668 | - | 3,668 |
| Macon, Ga. | 1,824 | 174 | - | - | 1,998 | 502 | 492 | 10 | 1,005 | 3,003 | - | 3,006 | + 20 | 3,023 |
| Madison, Wisc. | 9,999 | 360 | - | - | 10,359 | 2,196 | 2,463 | 206 | 4,865 | 15,224 | 1,486 | 16,710 | - 72 | 16,638 |
| Sioux Falls, S. D. | 8,216 | 158 | - | - | 8,374 | 641 | 494 | 144 | 1,279 | 9,653 | 600 | 10,253 | - 225 | 10,028 |
| South Bend, Ind. | 2,766 | 152 | - | - | 2,918 | 1,039 | - | 516 | 1,555 | 4,473 | 1,000 | 5,473 | - 991 | 4,482 |
| Springfield, Mo. | 3,977 | 770 | - | - | 4,747 | 860 | 155 | 265 | 1,280 | 6,027 | 265 | 6,292 | - 350 | 5,942 |
| Waterbury, Conn. | 4,346 | 91 | | | 4,437 | 4 | 1,960 | 222 | 2,186 | 6,623 | 25 | 6,648 | + 301 | 6,949 |
| Subtotal | 110,676 | 4,705 | 652 | - | 116,033 | 17,970 | 15,297 | 2,756 | 36,023 | 152,056 | 11,552 | 163,606 | - 1,997 | 161,611 |
| Percent | 72.79 | 3.09 | 0.43 | - | 76.31 | 11.82 | 10.06 | 1.81 | 23.69 | 100.00 | | | | |
| 250,000 to 500,000: | | | | | | | | | | | | | | |
| Albuquerque, N. M. | 11,061 | 629 | - | - | 11,690 | 2,692 | 52 | 276 | 3,020 | 14,710 | 2,809 | 17,519 | + 725 | 18,244 |
| Charleston, W. Va. | 2,642 | 257 | - | - | 2,899 | 363 | 1,023 | - | 1,386 | 4,285 | - | 4,285 | + 125 | 4,410 |
| Charlotte, N. C. | 3,676 | 144 | - | - | 3,820 | - | 1,857 | - | 1,857 | 5,677 | - | 5,677 | + 202 | 5,879 |
| Jacksonville, Fla. | 20,439 | 427 | 3,336 | - | 24,204 | 2,234 | 1,634 | 1,997 | 5,865 | 30,069 | 1,673 | 31,742 | + 13,531 | 45,273 |
| Nashville, Tenn. | 18,250 | 1,401 | - | - | 19,651 | 1,813 | 85 | 198 | 2,096 | 21,747 | 654 | 22,401 | + 106 | 22,507 |
| Omaha, Nebr. | 16,080 | 1,987 | - | 197 | 18,264 | 5,003 | - | 344 | 5,347 | 23,611 | 2,760 | 26,371 | + 1,225 | 27,596 |
| Salt Lake City, Utah | 9,505 | 257 | - | - | 9,762 | 2,391 | 943 | 171 | 3,505 | 13,267 | - | 13,267 | - 222 | 13,045 |
| Tacoma, Wash. | 9,836 | - | - | - | 9,836 | 1,451 | 1,157 | 259 | 2,867 | 12,703 | - | 12,703 | + 1,026 | 13,729 |
| Tulsa, Okla. | 6,376 | 484 | 1,598 | - | 8,458 | 850 | 744 | 426 | 2,020 | 10,478 | 4,481 | 14,959 | + 857 | 15,816 |
| Wichita, Kans. | 7,627 | 418 | 359 | - | 8,404 | 7,842 | 362 | 840 | 9,044 | 17,448 | 6,659 | 24,107 | + 908 | 25,015 |
| Wilmington, Del. | 5,359 | 467 | 4,770 | - | 10,596 | 99 | 4,412 | 28 | 4,539 | 15,135 | 5,853 | 20,988 | - 970 | 20,018 |
| Subtotal | 110,851 | 6,471 | 10,065 | 197 | 127,584 | 24,738 | 12,269 | 4,539 | 41,546 | 169,130 | 24,889 | 194,019 | + 17,513 | 211,532 |
| Percent | 65.54 | 3.83 | 5.95 | 0.12 | 75.44 | 14.63 | 7.25 | 2.68 | 24.56 | 100.00 | | | | |
| 500,000 to 1,000,000: | | | | | | | | | | | | | | |
| Birmingham, Ala. | 7,108 | 2,283 | - | - | 9,391 | 4,592 | - | 969 | 5,561 | 14,952 | 3,300 | 18,252 | - 2,985 | 15,267 |
| Columbus, Ohio | 24,587 | 446 | - | - | 25,033 | 2,337 | 696 | 961 | 3,994 | 29,027 | 8,203 | 37,230 | + 523 | 37,753 |
| Denver, Colo. | 17,130 | - | 643 | - | 17,773 | 4,441 | 2,580 | 752 | 7,773 | 25,546 | 47 | 25,593 | - 120 | 25,473 |
| Honolulu, Hawaii | 12,090 | 4,368 | - | - | 16,458 | 3,493 | 85 | 474 | 4,052 | 20,510 | - | 20,510 | - 993 | 19,517 |
| New Orleans, La. | 17,311 | 539 | 2,926 | 1,437 | 22,213 | 5,259 | 5,476 | 1,796 | 12,531 | 34,744 | 9,074 | 43,818 | - 845 | 42,973 |
| Phoenix, Ariz. | 14,501 | - | - | - | 14,501 | 1,635 | 5,144 | 4,349 | 11,128 | 25,629 | 4,686 | 30,315 | - 1,467 | 28,848 |
| Providence, R. I. | 27,140 | 1,390 | 718 | - | 29,248 | 12 | 10,104 | 222 | 10,338 | 39,586 | 4,368 | 43,954 | - 118 | 43,836 |
| Subtotal | 119,867 | 9,026 | 4,287 | 1,437 | 134,617 | 21,769 | 24,085 | 9,523 | 55,377 | 189,994 | 29,678 | 219,672 | - 6,005 | 213,667 |
| Percent | 63.09 | 4.75 | 2.25 | 0.76 | 70.85 | 11.46 | 12.68 | 5.01 | 29.15 | 100.00 | | | | |
| 1,000,000 and over: | | | | | | | | | | | | | | |
| Baltimore, Md. | 40,512 | 4,602 | 5,558 | 351 | 51,023 | 865 | 13,016 | 442 | 14,323 | 65,346 | 4,840 | 70,186 | + 345 | 70,531 |
| Buffalo, N. Y. | 21,943 | 781 | 4,637 | - | 27,361 | 5,069 | 18,223 | 1,277 | 24,569 | 51,930 | 12,774 | 64,704 | + 2,219 | 66,923 |
| Chicago, Ill. | 193,293 | 39,080 | 18,426 | 2,208 | 253,007 | 30,443 | 5,928 | 2,741 | 39,112 | 292,119 | 83,073 | 375,192 | - 8,127 | 367,065 |
| Houston, Tex. | 36,799 | 687 | - | - | 37,486 | 20,674 | 6,387 | 3,766 | 30,827 | 68,313 | 19,224 | 87,537 | - 5,406 | 82,131 |
| Los Angeles, Calif. | 153,767 | 3,686 | - | 281 | 157,734 | 11,202 | 44,776 | 15,262 | 71,240 | 228,974 | 10,720 | 239,694 | - 8,961 | 230,733 |
| Minneapolis-St. Paul, Minn. | 53,995 | 1,072 | - | - | 55,067 | 19,945 | 6,832 | 3,175 | 29,952 | 85,019 | 11,495 | 96,514 | - 2,676 | 93,838 |
| Philadelphia, Pa. | 52,480 | 1,999 | 28,034 | 1,566 | 84,079 | 429 | 26,987 | 7,215 | 34,631 | 118,710 | 14,601 | 133,311 | + 700 | 134,011 |
| Subtotal | 552,789 | 51,907 | 56,655 | 4,406 | 665,757 | 88,627 | 122,149 | 33,878 | 244,654 | 910,411 | 156,727 | 1,067,138 | - 21,906 | 1,045,232 |
| Percent | 60.72 | 5.70 | 6.22 | 0.49 | 73.13 | 9.73 | 13.42 | 3.72 | 26.87 | 100.00 | | | | |
| Total, all SMSA's | 894,183 | 72,109 | 71,659 | 6,040 | 1,043,991 | 153,104 | 173,800 | 50,696 | 377,600 | 1,421,591 | 222,846 | 1,644,437 | - 12,395 | 1,632,042 |
| Percent | 62.90 | 5.07 | 5.04 | 0.43 | 73.44 | 10.77 | 12.22 | 3.57 | 27.56 | 100.00 | | | | |

TABLE 4

ROAD AND STREET EXPENDITURES OF 46 SELECTED STANDARD METROPOLITAN STATISTICAL AREAS IN 1960
(In $1,000's)

| Standard Metropolitan Statistical Areas by Population Groups | Capital Outlay | | | | | | Total Capital Outlay | Maintenance, Administration, Operation, etc.[1] | Interest | Total Expenditures | Debt Retirement | Total Disbursements |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | On State Administered Highways | | | On Local Roads and Streets | | | | | | | | |
| | Rural | Urban | Total | Rural | Urban | Total | | | | | | |
| Under 250,000: | | | | | | | | | | | | |
| Atlantic City, N. J. | 1,044 | 51 | 1,095 | 165 | 293 | 458 | 1,553 | 4,608 | 298 | 6,459 | 406 | 6,865 |
| Bay City, Mich. | 3,773 | 99 | 3,872 | 41 | 745 | 786 | 4,658 | 1,614 | 14 | 6,286 | 90 | 6,376 |
| Cedar Rapids, Iowa | 907 | 370 | 1,277 | 888 | 911 | 1,799 | 3,076 | 2,552 | 56 | 5,684 | 279 | 5,963 |
| Charleston, S. C. | 2,817 | 353 | 3,170 | 99 | 84 | 183 | 3,353 | 1,334 | - | 4,687 | - | 4,687 |
| Eugene, Ore. | 7,849 | - | 7,849 | 1,763 | 1,135 | 2,898 | 10,747 | 3,084 | 54 | 13,885 | 246 | 14,131 |
| Fargo, N. D. | 10,265 | 985 | 11,250 | 1,572 | 1,552 | 3,124 | 14,374 | 2,361 | 273 | 17,008 | 536 | 17,544 |
| Fitchburg-Leominster, Mass. | 99 | - | 99 | 46 | 206 | 252 | 351 | 1,289 | 12 | 1,652 | 140 | 1,792 |
| Fort Wayne, Ind. | 1,952 | 205 | 2,157 | 809 | 599 | 1,408 | 3,565 | 1,875 | 97 | 5,537 | 307 | 5,844 |
| Great Falls, Mont. | 2,834 | 70 | 2,904 | 42 | 241 | 283 | 3,187 | 1,443 | 241 | 4,871 | 475 | 5,346 |
| Jackson, Miss. | 2,287 | 478 | 2,765 | 505 | 1,033 | 1,538 | 4,303 | 2,598 | 295 | 7,196 | 2,485 | 9,681 |
| Las Vegas, Nev. | 3,011 | 24 | 3,035 | 180 | 853 | 1,033 | 4,068 | 1,830 | 41 | 5,939 | 234 | 6,173 |
| Lewiston-Auburn, Maine | 4 | 110 | 114 | - | 110 | 110 | 224 | 795 | 199 | 1,218 | 42 | 1,260 |
| Lexington, Ky. | 1,492 | 73 | 1,565 | - | - | - | 1,565 | 1,138 | - | 2,703 | - | 2,703 |
| Little Rock-No. Little Rock, Ark. | 4,739 | 12,698 | 17,437 | 99 | 1,530 | 1,629 | 19,066 | 2,964 | 141 | 22,171 | 345 | 22,516 |
| Lynchburg, Va. | 1,243 | 168 | 1,411 | - | 604 | 604 | 2,015 | 1,229 | 120 | 3,364 | 304 | 3,668 |
| Macon, Ga. | 1,559 | - | 1,559 | 345 | 135 | 480 | 2,039 | 915 | 24 | 2,978 | 45 | 3,023 |
| Madison, Wisc. | 6,127 | 166 | 6,293 | 2,006 | 3,129 | 5,135 | 11,428 | 3,914 | 227 | 15,569 | 1,069 | 16,638 |
| Sioux Falls, S. D. | 4,428 | 2,782 | 7,210 | 1,004 | 241 | 1,245 | 8,455 | 1,539 | 14 | 10,008 | 20 | 10,028 |
| South Bend, Ind. | 153 | 16 | 169 | 477 | 436 | 913 | 1,082 | 2,800 | 25 | 3,907 | 575 | 4,482 |
| Springfield, Mo. | 2,911 | 642 | 3,553 | 67 | 307 | 374 | 3,927 | 1,656 | 29 | 5,612 | 330 | 5,942 |
| Waterbury, Conn. | 3,216 | - | 3,216 | 104 | 245 | 349 | 3,565 | 3,089 | 103 | 6,757 | 192 | 6,949 |
| Subtotal | 62,710 | 19,290 | 82,000 | 10,212 | 14,389 | 24,601 | 106,601 | 44,627 | 2,263 | 153,491 | 8,120 | 161,611 |
| Percent | 40.85 | 12.57 | 53.42 | 6.65 | 9.38 | 16.03 | 69.45 | 29.07 | 1.48 | 100.00 | | |
| 250,000 to 500,000: | | | | | | | | | | | | |
| Albuquerque, N. M. | 1,031 | 9,157 | 10,188 | 101 | 2,268 | 2,369 | 12,557 | 3,726 | 469 | 16,752 | 1,492 | 18,244 |
| Charleston, W. Va. | 655 | - | 655 | - | 37 | 37 | 692 | 3,426 | 116 | 4,234 | 176 | 4,410 |
| Charlotte, N. C. | 1,436 | 396 | 1,832 | - | 428 | 428 | 2,260 | 3,140 | 181 | 5,581 | 298 | 5,879 |
| Jacksonville, Fla. | 17,862 | 6,338 | 24,200 | 143 | 1,058 | 1,201 | 25,401 | 7,898 | 5,011 | 38,310 | 6,963 | 45,273 |
| Nashville, Tenn. | 7,465 | 8,694 | 16,159 | 626 | 1,126 | 1,752 | 17,911 | 3,454 | 276 | 21,641 | 866 | 22,507 |
| Omaha, Nebr. | 8,205 | 2,740 | 10,945 | 3,156 | 3,708 | 6,864 | 17,809 | 6,510 | 402 | 24,721 | 2,875 | 27,596 |
| Salt Lake City, Utah | 7,931 | 174 | 8,105 | 778 | 685 | 1,463 | 9,568 | 3,477 | - | 13,045 | - | 13,045 |
| Tacoma, Wash. | 2,044 | 4,629 | 6,673 | - | 2,795 | 2,795 | 9,468 | 3,736 | 179 | 13,383 | 346 | 13,729 |
| Tulsa, Okla. | 3,347 | 419 | 3,766 | 1,739 | 1,856 | 3,595 | 7,361 | 5,151 | 1,757 | 14,269 | 1,547 | 15,816 |
| Wichita, Kans. | 3,658 | 2,894 | 6,552 | 1,152 | 4,228 | 5,380 | 11,932 | 4,637 | 1,330 | 17,899 | 7,116 | 25,015 |
| Wilmington, Del. | 6,342 | 1,958 | 8,300 | 48 | 943 | 991 | 9,291 | 6,336 | 1,145 | 16,772 | 3,246 | 20,018 |
| Subtotal | 59,976 | 37,399 | 97,375 | 7,743 | 19,132 | 26,875 | 124,250 | 51,491 | 10,866 | 186,607 | 24,925 | 211,532 |
| Percent | 32.14 | 20.04 | 52.18 | 4.15 | 10.25 | 14.40 | 66.58 | 27.60 | 5.82 | 100.00 | | |
| 500,000 to 1,000,000: | | | | | | | | | | | | |
| Birmingham, Ala. | 4,988 | 103 | 5,091 | 2,718 | 2,251 | 4,969 | 10,060 | 4,144 | 217 | 14,421 | 846 | 15,267 |
| Columbus, Ohio | 7,697 | 9,822 | 17,519 | 1,543 | 1,892 | 3,435 | 20,954 | 7,196 | 829 | 28,979 | 8,774 | 37,753 |
| Denver, Colo. | 5,920 | 5,033 | 10,953 | 1,625 | 1,677 | 3,302 | 14,255 | 10,438 | 325 | 25,018 | 455 | 25,473 |
| Honolulu, Hawaii | 2,877 | 4,584 | 7,461 | - | 3,334 | 3,334 | 10,795 | 7,801 | 475 | 19,071 | 446 | 19,517 |
| New Orleans, La. | 4,051 | 12,478 | 16,529 | 1,693 | 3,594 | 5,287 | 21,816 | 9,892 | 5,627 | 37,335 | 5,638 | 42,973 |
| Phoenix, Ariz. | 2,917 | 6,046 | 8,963 | 8,153 | 3,117 | 11,270 | 20,233 | 6,767 | 440 | 27,440 | 1,408 | 28,848 |
| Providence, R. I. | 3,197 | 20,518 | 23,715 | 459 | 4,372 | 4,831 | 28,546 | 12,793 | 459 | 41,798 | 2,038 | 43,836 |
| Subtotal | 31,647 | 58,584 | 90,231 | 16,191 | 20,237 | 36,428 | 126,659 | 59,031 | 8,372 | 194,062 | 19,605 | 213,667 |
| Percent | 16.31 | 30.19 | 46.50 | 8.34 | 10.43 | 18.77 | 65.27 | 30.42 | 4.31 | 100.00 | | |
| 1,000,000 and over: | | | | | | | | | | | | |
| Baltimore, Md. | 10,812 | 37 | 10,849 | 4,146 | 15,761 | 19,907 | 30,756 | 27,208 | 4,245 | 62,209 | 8,322 | 70,531 |
| Buffalo, N. Y. | 10,100 | 9,193 | 19,293 | 4,346 | 6,806 | 11,152 | 30,445 | 22,304 | 3,719 | 56,468 | 10,455 | 66,923 |
| Chicago, Ill. | 46,414 | 120,089 | 166,503 | 8,573 | 26,159 | 34,732 | 201,235 | 101,616 | 31,450 | 334,301 | 32,764 | 367,065 |
| Houston, Tex. | - | 35,954 | 35,954 | 2,548 | 12,087 | 14,635 | 50,589 | 16,949 | 4,403 | 71,941 | 10,190 | 82,131 |
| Los Angeles, Calif. | 38,885 | 59,884 | 98,769 | 15,494 | 31,647 | 47,141 | 145,910 | 78,583 | 1,692 | 226,185 | 4,548 | 230,733 |
| Minneapolis-St. Paul, Minn. | 7,923 | 33,772 | 41,695 | 6,046 | 11,761 | 17,807 | 59,502 | 27,096 | 1,511 | 88,109 | 5,729 | 93,838 |
| Philadelphia, Pa. | 23,110 | 20,642 | 43,752 | 3,512 | 12,195 | 15,707 | 59,459 | 46,787 | 11,259 | 117,505 | 16,506 | 134,011 |
| Subtotal | 137,244 | 279,571 | 416,815 | 44,665 | 116,416 | 161,081 | 577,896 | 320,543 | 58,279 | 956,718 | 88,514 | 1,045,232 |
| Percent | 14.35 | 29.22 | 43.57 | 4.67 | 12.17 | 16.84 | 60.41 | 33.50 | 6.09 | 100.00 | | |
| Total all SMSA's | 291,577 | 394,844 | 686,421 | 78,811 | 170,174 | 248,985 | 935,406 | 475,692 | 79,780 | 1,490,878 | 141,164 | 1,632,042 |
| Percent | 19.56 | 26.48 | 46.04 | 5.29 | 11.41 | 16.70 | 62.74 | 31.91 | 5.35 | 100.00 | | |

[1]Includes parking, policing, and allied functions.

interest on highway debt for $80 million. Total expenditures, exclusive of debt retirement, were slightly less than $1.5 billion.

The estimated 1960 earnings from road-user taxes, tolls, and parking fees in these 46 SMSA's are set forth in Table 5. The estimates of vehicle-miles traveled within them total to nearly 122 billion. The total estimated earnings were $1,650 million.

By far the greatest block of revenues generated is that of State motor-fuel taxes and motor vehicle registration and other fees, which totaled to $1,001 million. Payments of tolls on State toll facilities amounted to nearly $22 million, bringing the total in State taxes, fees, and tolls to $1,072 million, or 65.0 percent of the total earnings. Federal motor-fuel and excise taxes generated ($499 million) were slightly less than one-half the State total. They do not include the 10 percent excise tax on automobiles, the proceeds of which do not accrue to the highway trust fund. The earnings of local taxes and tolls were $78 million, a small but significant contribution.

The last column in Table 5 gives the ratio of user earnings to expenditures in 1960. In 20 of the 46 SMSA's expenditures were greater than earnings; in 26 earnings exceeded expenditures. Ratios in the larger places exceed those in the smaller places. The ratio for the whole group is 1.11.

The outcome of this preliminary examination of earnings and expenditures in SMSA's is the finding that road-user taxes, fees, and tolls generated are of the same order of magnitude as expenditures. In a year of much greater construction activity expenditures in these SMSA's might well exceed earnings. This would be illusory, however, because the accelerated construction of long-lived facilities builds for the future, and such peaks are leveled out in the long run.

Comparison of Tables 3 and 5 reveals the fact that, although the earnings were $1,650 million, the amount of road-user taxes, fees, and tolls applied to roads and streets was only $1,044 million. The ratio of user earnings to user revenues applied is 1.58. Two inferences can be drawn from this showing. One is that the cities, and even the partly rural SMSA's, are not getting their share of user-tax revenues in relation to earnings, in comparison with the rural areas. The other is that, as long as substantial amounts of local nonuser revenues are used for local street purposes, user earnings can exceed expenditures only if user revenues applied are considerably less than earnings.

It is difficult to pass judgment on this situation. The practice of using local nonuser revenues, including benefit assessments, for at least a part of the cost of local roads and streets, although condemned by some students, retains popular acceptance as well as the approval of many who have studied the subject. The current trend is for the urban places to receive an increasing share of motor vehicle tax proceeds, chiefly through the Federal and State programs of improvement of urban Interstate highways and other urban connections of Federal-aid and State highways. For the urban places to receive an exact return of the user tax earnings attributable to them would be too restrictive a policy. It is better for both State and Federal governments to have some leeway for the exercise of judgment as to where the needs for highway improvement are greatest.

Imputed Costs. — Where highway-related costs such as expenses of traffic policing, street lighting, and storm sewers can be identified, they may be accepted as a part of urban street costs, although close analysis would reveal that householders, business establishments, and pedestrians have a large stake in these services. It is not uncommon, however, when interests hostile to highways or motor vehicles are at stake, for the highway tax bill to be inflated by items of cost that never appear on the books of account, never have to be paid to anybody by anyone (32, pp. 5-9).

Imputed interest has caused much controversy over the years, perhaps because of misunderstanding and lack of communication. Annual expenditures for capital outlay, interest, maintenance, and operation may be listed for a series of years, and when so listed they give a true account of costs for highways or any other activity, except for the fact that the story is seldom ended at any cutoff year. For analytical purposes it is advantageous to substitute annual cost calculations for lists of expenditures, in order to impart uniformity, order, and continuity to the series. It should

TABLE 5

ESTIMATED MOTOR-VEHICLE USER-TAX AND TOLL EARNINGS GENERATED BY TRAVEL AND VEHICLE OWNERSHIP IN 46 SELECTED STANDARD METROPOLITAN STATISTICAL AREAS IN 1960, AT 1960 TAX RATES AND TOLLS
(In $1,000's)

| Standard Metropolitan Statistical Area by Population Group | Vehicle-Miles of Travel Within the SMSA | Collecting Agencies: Federal Government: Excise Taxes of the Federal-Highway Trust Fund[2] | State Agencies[1]: Motor Fuel and Vehicle Taxes and Fees | State Agencies[1]: Tolls | State Agencies[1]: Total State Taxes and Fees | Local Governments[1]: Motor Fuel and Vehicle Taxes and Fees[3] | Local Governments[1]: Tolls | Local Governments[1]: Total Local Taxes and Fees | Total User Taxes on Highway Use in SMSA | Ratio of User Earnings to Expend-itures |
|---|---|---|---|---|---|---|---|---|---|---|
| | (thousands) | | | | | | | | | |
| Under 250,000: | | | | | | | | | | |
| Atlantic City, N. J. | 1,175,000 | 4,690 | 7,102 | 380 | 7,482 | 273 | - | 273 | 12,445 | 1.93 |
| Bay City, Mich. | 425,000 | 1,751 | 3,354 | - | 3,354 | - | - | - | 5,105 | 0.81 |
| Cedar Rapids, Iowa | 501,680 | 2,125 | 4,988 | - | 4,988 | 210 | - | 210 | 7,323 | 1.29 |
| Charleston, S. C. | 715,000 | 3,103 | 5,332 | - | 5,332 | - | - | - | 8,435 | 1.80 |
| Eugene, Ore. | 643,400 | 2,597 | 6,456 | - | 6,456 | 276 | - | 276 | 9,329 | 0.67 |
| Fargo, N. Dak. | 451,962 | 1,962 | 3,835 | - | 3,835 | - | - | - | 5,797 | 0.34 |
| Fitchburg-Leominster, Mass. | 426,000 | 1,492 | 2,286 | - | 2,286 | 1,012 | - | 1,012 | 4,790 | 2.90 |
| Fort Wayne, Ind. | 581,960 | 2,399 | 5,072 | - | 5,072 | 95 | - | 95 | 7,566 | 1.37 |
| Great Falls, Mont. | 273,057 | 1,048 | 2,174 | - | 2,174 | 137 | - | 137 | 3,359 | 0.69 |
| Jackson, Miss. | 589,712 | 2,526 | 5,112 | - | 5,112 | 137 | - | 137 | 7,775 | 1.08 |
| Las Vegas, Nev. | 358,823 | 1,722 | 3,658 | - | 3,658 | 197 | - | 197 | 5,577 | 0.94 |
| Lewiston-Auburn, Maine | 174,125 | 622 | 1,650 | 272 | 1,922 | 134 | - | 134 | 2,678 | 2.20 |
| Lexington, Ky. | 432,700 | 1,832 | 3,666 | - | 3,666 | 81 | - | 81 | 5,579 | 2.06 |
| Little Rock-No. Little Rock, Ark. | 794,700 | 3,876 | 7,330 | - | 7,330 | 188 | - | 188 | 11,394 | 0.51 |
| Lynchburg, Va. | 423,912 | 1,837 | 3,220 | - | 3,220 | 260 | - | 260 | 5,317 | 1.58 |
| Macon, Ga. | 451,870 | 1,721 | 3,273 | - | 3,273 | 174 | - | 174 | 5,168 | 1.74 |
| Madison, Wisc. | 911,610 | 3,916 | 7,436 | - | 7,436 | 360 | - | 360 | 11,712 | 0.75 |
| Sioux Falls, S. Dak. | 340,451 | 1,435 | 3,027 | - | 3,027 | 158 | - | 158 | 4,620 | 0.46 |
| South Bend, Ind. | 570,090 | 2,301 | 4,688 | - | 4,888 | 152 | - | 152 | 7,341 | 1.88 |
| Springfield, Mo. | 659,096 | 2,505 | 2,962 | - | 2,962 | 770 | - | 770 | 6,237 | 1.11 |
| Waterbury, Conn. | 523,283 | 2,146 | 4,208 | - | 4,208 | 26 | - | 26 | 6,380 | 0.94 |
| Subtotal | 11,424,431 | 47,606 | 91,029 | 652 | 91,681 | 4,640 | - | 4,640 | 143,927 | 0.94 |
| Percent | | 33.08 | 63.25 | 0.45 | 63.70 | 3.22 | - | 3.22 | 100.00 | |
| 250,000 to 500,000: | | | | | | | | | | |
| Albuquerque, N. Mex. | 827,424 | 3,531 | 7,109 | - | 7,109 | 629 | - | 629 | 11,269 | 0.67 |
| Charleston, W. Va. | 814,431 | 3,504 | 8,734 | - | 8,734 | 257 | - | 257 | 12,495 | 2.95 |
| Charlotte, N. C. | 675,129 | 2,741 | 6,462 | - | 6,462 | 144 | - | 144 | 9,347 | 1.67 |
| Jacksonville, Fla. | 1,807,115 | 7,297 | 15,715 | 3,338 | 19,053 | 427 | - | 427 | 26,777 | 0.70 |
| Nashville, Tenn. | 1,208,996 | 5,147 | 10,389 | - | 10,389 | 1,401 | - | 1,401 | 16,937 | 0.78 |
| Omaha, Nebr. | 1,842,338 | 7,585 | 14,988 | - | 14,988 | 1,987 | 197 | 2,184 | 24,757 | 1.00 |
| Salt Lake City, Utah | 1,155,000 | 4,929 | 8,908 | - | 8,908 | 257 | - | 257 | 14,094 | 1.08 |
| Tacoma, Wash. | 1,281,000 | 5,087 | 12,035 | - | 12,035 | - | - | - | 17,122 | 1.28 |
| Tulsa, Okla.[4] | 1,436,382 | 5,931 | 15,757 | 1,598 | 17,355 | 484 | - | 484 | 23,770 | 1.67 |
| Wichita, Kans. | 1,381,796 | 5,514 | 8,846 | 359 | 9,205 | 418 | - | 418 | 15,137 | 0.85 |
| Wilmington, Del. | 1,586,247 | 6,554 | 11,000 | 4,770 | 15,770 | 467 | - | 467 | 22,791 | 1.42 |
| Subtotal | 14,015,858 | 57,820 | 119,943 | 10,065 | 130,008 | 6,471 | 197 | 6,668 | 194,496 | 1.05 |
| Percent | | 29.73 | 61.67 | 5.17 | 66.84 | 3.33 | 0.10 | 3.43 | 100.00 | |
| 500,000 to 1,000,000: | | | | | | | | | | |
| Birmingham, Ala. | 2,052,312 | 8,140 | 14,661 | - | 14,661 | 2,283 | - | 2,283 | 25,084 | 1.74 |
| Columbus, Ohio | 2,696,374 | 10,308 | 23,291 | - | 23,291 | 446 | - | 446 | 34,045 | 1.17 |
| Denver, Colo. | 3,500,000 | 14,354 | 26,939 | 643 | 27,582 | - | - | - | 41,936 | 1.68 |
| Honolulu, Hawaii | 1,123,090 | 4,544 | 8,903 | - | 8,903 | 4,368 | - | 4,368 | 17,815 | 0.93 |
| New Orleans, La. | 1,940,483 | 9,136 | 16,690 | 2,926 | 19,616 | 539 | 1,437 | 1,976 | 30,730 | 0.82 |
| Phoenix, Ariz. | 3,083,304 | 13,157 | 21,430 | - | 21,430 | - | - | - | 34,567 | 1.26 |
| Providence, R. I. | 3,401,100 | 11,997 | 27,150 | 718 | 27,868 | 1,390 | - | 1,390 | 41,255 | 0.99 |
| Subtotal | 17,796,663 | 71,638 | 139,064 | 4,287 | 143,351 | 9,026 | 1,437 | 10,463 | 225,452 | 1.16 |
| Percent | | 31.78 | 61.68 | 1.90 | 63.58 | 4.00 | 0.64 | 4.64 | 100.00 | |
| 1,000,000 and over: | | | | | | | | | | |
| Baltimore, Md. | 5,965,707 | 24,796 | 48,698 | 5,558 | 54,256 | 4,602 | 351 | 4,953 | 84,005 | 1.35 |
| Buffalo, N. Y. | 3,417,680 | 13,638 | 31,416 | 4,637 | 36,053 | 781 | - | 781 | 50,472 | 0.89 |
| Chicago, Ill. | 19,210,133 | 76,656 | 135,788 | 18,426 | 154,214 | 39,080 | 2,208 | 41,288 | 272,158 | 0.81 |
| Houston, Texas | 4,265,000 | 17,958 | 36,935 | - | 36,935 | 687 | - | 687 | 55,580 | 0.77 |
| Los Angeles, Calif. | 27,808,000 | 117,625 | 264,876 | - | 264,876 | 3,686 | 281 | 3,967 | 386,468 | 1.71 |
| Minneapolis-St. Paul, Minn. | 5,500,000 | 22,557 | 42,210 | - | 42,210 | 1,072 | - | 1,072 | 65,839 | 0.75 |
| Philadelphia, Pa. | 12,313,914 | 48,908 | 90,797 | 28,034 | 118,831 | 1,999 | 1,613 | 3,612 | 171,351 | 1.46 |
| Subtotal | 78,480,434 | 322,138 | 650,720 | 56,655 | 707,375 | 51,907 | 4,453 | 56,360 | 1,085,873 | 1.13 |
| Percent | | 29.67 | 59.92 | 5.22 | 65.14 | 4.78 | 0.41 | 5.19 | 100.00 | |
| Total all SMSA's | 121,717,386 | 499,202 | 1,000,756 | 71,659 | 1,072,415 | 72,044 | 6,087 | 78,131 | 1,649,748 | 1.11 |
| Percent | | 30.26 | 60.66 | 4.34 | 65.00 | 4.37 | 0.37 | 4.74 | 100.00 | |

[1]Includes earnings from State motor-fuel taxes at estimated consumption rates per mile of travel, and registration, operator license, and other fees that were either recorded collections in each area, or computed on basis of vehicle ownership in that SMSA. Local highway-user imposts include the proceeds from motor-fuel, bus and wheel taxes, automobile and truck licenses, and other fees levied on highway users within those jurisdictions.
[2]Includes taxes on motor fuel, truck, bus, and trailer excise, tires, tubes, and tread rubber, and vehicle-use taxes. Does not include automobile excise, parts and accessories, and lubricating oil taxes, which are general fund revenues.
[3]Includes parking fees.
[4]Excludes Osage County.

not be forgotten that this is a substitution, an abstraction from reality that brings its own uncertainties, in the form of an assumed rate of interest and an assumed term of amortization.

A fact that is often disregarded is that when capital outlay is paid for out of current revenues the interest, at whatever rate, is prepaid. This can be demonstrated by pointing out that the taxpayer, in supplying say $1,000 for this purpose, is laying on the line an amount that, at 4 percent interest, will be worth $1,480 in 10 years, $3,245 in 30 years. At 7 percent its value will be $1,970 in 10 years. This means that the taxpayer should not be made to pay an interest charge on the money he has supplied for direct capital outlay. Conversely, it means that the taxpayer has a right to expect a return in benefits from the highway investment at least equal to the return he would receive from an alternative investment of the $1,000.

This point can be demonstrated by an exercise in which one imagines a State highway department in possession, on January 1, of $10,000,000 in user-tax proceeds available for use in highway construction. Wishing to have its transactions conform to the annual-cost canon, the department does not use the money in this way. Instead, on January 1, it borrows $10,000,000 on a 30-year annuity loan at 4 percent interest. At this rate the recovery factor is 0.0578301, so that the department is obligated to an annual debt-service charge of $578,301 for 30 years. To meet this obligation it invests the $10,000,000 of user-tax money, on January 1, in a 30-year annuity loan at 4 percent interest. This loan will yield an annual income of $578,301. Thus the transaction washes out. The end result of this ritual dance is as if the original $10,000,000 had been used directly for highway construction. The interest, in short, is prepaid.

Somewhat more subtle is the contention that the motorists should pay the equivalent of a rental on the present value of the land occupied by roads and streets, calculated presumably on the value base of the abutting land. In response to this one may inquire what would be the value of the land on Manhattan Island if there were no streets there. One may point out that most highway right-of-way has been paid for and become sunk costs many years ago; that right-of-way currently purchased is being paid for, chiefly out of user-tax proceeds; and that no institution, whether government or private firm, needs to earn a return on investments that have been amortized. The recital of these facts will not deter the advocates of such charges, but it serves to highlight the essential frivolity of the proposal.

Of equal inconsequence is the proposal that the road users should pay taxes on the value of the land and the highway improvements built upon it. For any ordinary road or street the value added to the tax base by the presence of roads giving access to land and improvements far outweights the imputed taxable value of the road itself. The case of modern freeways and other large-scale highway improvements is somewhat different in that extensive land acquisitions and demolitions may cause dislocations resulting, at least temporarily, in "loss of ratables."

There are, however, mitigating factors even in the case of freeways. For each parcel of land and improvements a price equal at least to its fair market value was paid. The impression seems to prevail that the money received in such transactions is squandered the next day at the races. It is more likely, however, that most—indeed, nearly all—of it is reinvested in new residential property or income-producing commercial and industrial property. It may not be in the immediate area; it may even be outside the jurisdiction in which the land was sold; but the money does not vanish into thin air. Furthermore, the reorganization of land uses attendant on major highway improvements, described by Garrison (33, p. 22) as "... the more efficient operation of vehicles, firms, and households, given better highway facilities," is almost certain to have a favorable effect on the tax base of the urban area as a whole (34). Specific hardship areas in the midst of general improvement can be cured by specific action. Tax equivalents are a remedy for this sort of dislocation, but they are applied where needed, and not to the whole body politic.

These items of imputed highway tax responsibility are frequently advanced as a means of equalizing the competitive position of alternative modes of transportation or,

as in the case of the rapid-transit controversy, of finding funds with which to shore up the financial position of the competing mode. Railways and transit lines, being public utilities, can be relieved of onerous taxes, although Meyer et al (35, p. 267) question the desirability of doing so. As for subsidies for the support of public transit, there would be great advantages to giving them as broad a tax base as possible, rather than incurring enmity by taxing the highway users to subsidize the nonusers.

Summary. —The foregoing leads to the following conclusions about the relation of present-day highway financing to the problem of congestion tolls:

1. Highway expenditures per mile of travel are significantly greater in rural areas than in urban areas; in this sense the urban user may be said to "subsidize" the rural user.

2. System for system, costs, per mile of travel, of urban highways and streets are lower than rural highway costs. At the very top level there is an apparent reversal, in that extraordinary expenditures for right-of-way and structures cause the costs per vehicle-mile of urban expressways to exceed somewhat those of their rural counterparts. This disparity, being of the order of 8 to 18 percent, is not such as to indicate the necessity for revolutionary changes in urban highway financing.

3. Comparison of income, expenditures, and user-tax earnings of 24 individual urban areas (SMSA's) indicates that urban users are paying their way in generated user-tax proceeds. The cities, however, do not receive State road-user tax revenues in proportion to their earnings.

4. The shortage of State motor vehicle revenues is counterbalanced by the continued use of benefit assessments, ad valorem property taxes, and local general funds for the construction and maintenance of ordinary city streets, a practice having the sanction of tradition and (apparently) popular support.

5. There is little to be said in favor of imputed interest, rental, and tax costs that would inflate the highway tax burden far beyond the actual costs of owning and operating a highway system. There are more practicable and more equitable means of improving the competitive position of competing modes of transportation.

## Some Notes on Urban Travel

It is a popular theme nowadays to dilate on the horrors of motor vehicle traffic congestion in cities and to paint the picture of a day when all traffic will grind to a halt. Because cases of severe congestion are more easily remembered than the more normal case of slow but steady traffic flow, these frightful images are generally well received. Wisecracks about the alleged hazards and delays of the Hollywood Freeway are always good for a laugh on television, whereas the greater hazards and delays of driving on the ordinary streets of that great city have not, apparently, engaged the attention of the mass media.

It seems likely that the terrors of urban traffic congestion have been somewhat exaggerated. For one thing, if urban driving were so unpleasant it would probably bring about its own cure out of the sheer revulsion of the motorists. It is quite plain that for the most part they do not mind it, or not very much. Why this should be so can be told by any experienced suburb-to-city commuter, either driver or rider. Stopping for a red light, although it annoys one and makes one long for a freeway, is not an unbearable experience. Severe traffic tie-ups occur only semioccasionally, can almost always be ascribed to a known cause, and can be endured with stoicism when they occur.

Patterns of Urban Travel. —It is well to review some of the characteristics of urban traffic that have a bearing on the problem of congestion and the congestion-toll proposals. One of the most important is the relation of trips to the central business district to all trips in the urban or metropolitan area. Smith (36, pp. 95-103) shows that even for transit trips the percentage to or from the downtown area is as low as 25 in larger cities like Chicago and Detroit. Smith's Table 21 (36, p. 95), based on origin-destination studies in 10 metropolitan areas, shows that the percentage of all person trips made to or from the CBD varies from 9.2 in Chicago to 23.5 in Charlotte,

N. C., and 34.8 percent in Washington, D. C., for which the delimited CBD is inordinately large in comparison with those of other cities. For auto trips the percentage varies from 3.5 in Chicago to 21.7 in Charlotte and 25.3 in Washington; for transit the variation extends from 25.1 percent in Detroit to 72.5 percent in Phoenix, Ariz.

In general, the more populous the metropolitan area, the smaller the proportion of trips beginning or ending in the downtown area. As the suburbs grow and the importance of subsidiary urban complexes increases, this trend will continue. Thus it is seen that the problem of congestion in the CBD is only a fraction of the urban transportation problem. All urban areas in this country are in reality auto-oriented, and the transportation planning for a great metropolitan area must recognize this fact.

Of perhaps greater pertinence to the question at issue here is the proportion of trips entering the CBD but having destinations elsewhere. Table 6, also taken from the Smith report (36, p. 101), gives the relevant percentages for six individual cities and for 67 cities, taken as a group, in which the Bureau of Public Roads was associated with origin-destination studies. For the 67 cities 55 percent of the vehicles entering the CBD were only passing through on their way to a destination elsewhere. Of the remaining cities, the lowest percentage, 51, is found in Kansas City, and the highest, 78 in New Orleans. These data serve to emphasize the fact that an adequate freeway network would deflect a substantial portion of the automobile traffic from the central business district, which should be skirted by an inner beltway.

The great problem of traffic service in the central business district is, of course, that of the peak-hour flow of commuters to and from work. Peaking characteristics are different on different modes of transportation. Vickrey (32, p. 12) states that commuter railways receive one-half their total traffic during the 15 peak hours of the week; that subways receive one-third their traffic during these hours; and that the percentage for expressway traffic to and from the central city is 18. Cummings (37) analyzed traffic on the six-lane Lodge-Ford expressway system in Detroit. In terms of the expected average ADT of 120,000 after 1967, he found that on the inbound lanes there will be 13 hr of the day during which three lanes are needed (over 3,000 in one direction). On the outbound lanes, because of sharper peaking, only 6 hr require three lanes. By Vickrey's standard, which Cummings deplores, the three peak hours will produce 25,140 vehicles or 21 percent of the daily traffic. (There are 6 hr when three lanes are required for both inbound and outbound traffic, and these account for 38 percent of the daily volume.)

The sharp peak-hour concentration of rapid-transit patronage restricts its use to situations where it can sustain a very heavy load during the morning and afternoon rush hours. A freeway system has the advantage of a broader traffic base. It can also accommodate bus transit, either as a part of the traffic stream or on separate controlled lanes if the prospective load factor warrants a high frequency of service.

These considerations and those previously discussed should suggest that the major problems of urban transportation are those of structure rather than of pricing. A well-designed expressway system culminating in an inner freeway loop will provide motorists the needed access to the central business district, protect that district from encroachment by traffic destined elsewhere, and relieve the arterial surface streets to serve a more local function with less congestion.

TABLE 6

WEEKDAY TRAFFIC PASSING THROUGH AND DESTINED FOR TYPICAL CENTRAL BUSINESS DISTRICTS[1]

| City | Percent of Total Vehicles Entering CBD | |
|---|---|---|
| | Vehicles Passing Through | Vehicles Having Destinations in CBD |
| St. Louis, Mo. | 62 | 38 |
| Kansas City, Mo. | 51 | 49 |
| Charlotte, N. C. | 66 | 34 |
| New Orleans, La. | 78 | 22 |
| Philadelphia, Pa. | 67 | 33 |
| Nashville, Tenn. | 75 | 25 |
| Bur. Pub. Roads (67 cities) | 55 | 45 |

[1]Sources: Compiled from origin-destination studies in each area, from data compiled by Bureau of Public Roads, published in Schmidt, R. E., and Campbell, M. Earl, "Highway Traffic Estimation," Eno Foundation for Highway Traffic Control, Saugatuck, Conn. (1956), and from Wilbur Smith and Associates, "Parking Study, Central Business District," New Orleans, Louisiana (1960). Data are for 24-hr periods except New Orleans, which are for 10 hr, 8:00 a.m. to 6:00 p.m. (Taken from Smith (36, p. 101).

In the great metropolitan areas the salvage or creation of rapid-transit systems may ease and simplify the freeway plan, reducing the number of lanes needed in corridors of tremendous peak load. To achieve such a structure requires coordination and balance, in which various disciplines unite to create a seemly product.

Self-Rationing Character of Urban Congestion. —The point has been made that present-day urban congestion is perhaps not intolerable because it is tolerated. Beckman (19, pp. 80-86) states the proposition that traffic tends to distribute itself in such wise that costs are equalized on alternative routes; and then proceeds to demonstrate, by means of the Pigou two-road theorem, that the equilibrium position does not produce the maximum benefit, which can only be achieved, according to the congestion-cost theorems, by marginal-cost pricing.

It is recognized by all that the pricing of any commodity or service tends to diminish the market for it. Thus, even at the present moderate levels of road-user taxes and tolls, some prospective users are priced out of the urban travel market, although perhaps more by the congestion costs than by the taxes themselves. One rather important item in the price of a trip to the CBD is often ignored—that of parking costs. In the office building district where the offices of the Bureau of Public Roads are situated the weekday price for all-day parking is around $1.50 to $2.00, with a monthly contract price of $25 or more. This is a deterrent, particularly to the commuter who drives alone. To a five-person carpool it is not an exorbitant charge; but car pooling in itself reduces congestion.

There is no doubt that the market for downtown parking space is confused by special situations and arrangements, such as free or low-priced curb parking, differentials in charges between public and private off-street parking facilities, free-parking-for-customers agreements, and free parking for individuals or groups in government establishments or private firms. Some of these arrangements are merely the absorption of the parking price in the charge for other services or the granting of fringe benefits (e.g., free parking space granted to an official or a group of workers can be regarded as a part of salary or wage because the space could otherwise be rented at the market). Problems of competition between public and private parking space can be resolved by suitable adjustment of public parking fees, both off-street and curb, and the restriction of curb parking to the space truly available for that use. The provision of downtown parking space adequate to the demand will reduce congestion by cutting down movement in search of space.

In the final result the influence of the "natural" forces of self-rationing, although producing a tolerable (or at least tolerated) situation, is not sufficient to produce the desired condition of free flow. Marginal-cost pricing based on congestion costs is urged as a means of bringing about this condition, either by a forced reduction of travel on a fixed system of arterial streets, with rapid transit receiving the commuters driven off the streets; or, alternatively, by using the proceeds of congestion tolls to construct a freeway system.

Perhaps much of the revulsion with which the congestion-toll proposal is greeted by motorists is due to the fact that it applies a market pricing mechanism to a set of costs that do not enter the market. Ordinarily the costs that determine market price in relation to demand are those of the enterpriser who manufactures the product or provides the service. But these costs are incurred by the customers, to themselves and to each other. The analogy is not quite good enough.

In particular, the value of time, the principal item of congestion costs, is so uncertain, so mercurial in character, that its use in building up the structure of marginal-congestion costs is questionable. It is true that the importance of time savings (as well as that of the even more elusive comfort and convenience element) in the demand for transportation improvements is so great that one is forced to deal with it in any sort of economic analysis, and to make dubious calculations of average unit values. The point should never be neglected, however, that time is of different unit value to different people and to the same person at different times and in different situations.

It will be recalled that in Mohring's derivation of the unit value of time as a function of speed by a refinement of the trade-off method (20, pp. 20-22), values

TABLE 7

ANALYSIS OF AN ASSUMED COMMUTER TRIP TO THE CENTRAL BUSINESS DISTRICT

| Distance Traveled (mi) | Elapsed Time (min) | | Average Speed | |
|---|---|---|---|---|
| | To End of Interval | During Interval | (mi/min) | (mph) |
| 0.0 | 0.0 | | | |
| | | 7.5 | 0.667 | 40.0 |
| 5.0 | 7.5 | | | |
| | | 10.0 | 0.500 | 30.0 |
| 10.0 | 17.5 | | | |
| | | 15.0 | 0.333 | 20.0 |
| 15.0 | 32.5 | | | |
| | | 10.0 | 0.250 | 15.0 |
| 17.5 | 42.5 | | | |
| | | 15.0 | 0.167 | 10.0 |
| 20.0 | 57.5 | | | |
| Avg. | - | - | 0.348 | 20.9 |

range from a slight negative at 20 mph to $67.82 per hour at a desired speed of 70 mph. The average of $2.80 was calculated on the basis of the normal distribution of free-moving vehicles on level tangent sections of high-speed two-lane highways, as given by the "Highway Capacity Manual" (16, p. 32). The average speed for this distribution is 48.5 mph. It is questionable whether the average unit values of time thus derived are applicable to the travel of commuters to and from the CBD in pursuit of their daily work trips.

This point may be made clearer by reference to Table 7, which gives the details, in distance, time, and speed of an imagined but perhaps fairly typical 20-mi commuter trip. During the first 5 mi the average speed is 40 mph; during the second 5 mi, 30; and during the third 5 mi, 20. During the next 2½-mi interval the average speed is 15 mph; and in the last 2½ mi it slows to 10 mph. The time for the trip is 57.5 min. If the construction of a freeway should enable this car to make the 20-mi trip at an average speed of 30 mph, the trip time would be 40 min, and the time savings would be 17.5 min. If time were valued at the AASHO rate of about $0.025 per min, the savings would be $0.44 per trip. The owner would be more than able to pay his share of the freeway cost under conventional Federal-State user-tax financing. But if he were told that he must pay Mohring's rates of $0.17 to $0.29 per mile (22, p. 17) for the last 2½ mi of his trip, he would regard the charge as grotesque. And indeed, these monumental tolls for the tag ends of suburb-to-city trips do seem to reflect a myopic view of the problems and purposes of highway transportation.

Progress in Relief of Urban Congestion.—Meyer, Kain, and Wohl (38, pp. 22-37) have called attention to the fact that the progressive development of freeway programs in the large cities, coupled with progress in routing and handling traffic through better traffic engineering and control, are beginning to show results in marked improvement of urban traffic flows, although volumes continue to increase. It is pertinent to quote directly:

> Excessive despair about urban transportation, however, may be more a reflection of a failure to realize anticipations or aspirations than of reality and also of a lag between effectuation of an improvement and its public realization. In several important respects, in fact, performance of urban transportation systems recently has held constant or improved, particularly in the last seven years when highway construction began to accelerate and the rate of growth in the automobile stock declined. For example, comparative travel time studies made in Washington, D. C., in 1947 and 1954 show virtually no change in peak-hour commuting time from the CBD despite a large increase in automobile travel and no large-scale highway construction. As a much greater proportion of Washington commuters are using private autos, and as travel times by auto have been better than those by public transit in Washington during any time period—prewar, wartime, or postwar—this means that the average level of performance as measured by commutation time in the Washington urban transportation system has probably improved.
>
> ******
>
> A recent study on urban transportation reports that by utilizing advanced traffic techniques and controls, Baltimore has achieved during the last eight years a threefold increase in traffic volume on some streets and savings in travel time up to 33 percent.

These writers also discuss the situation in Los Angeles, and give data illustrating the improvement in trip travel times in that city. It is possible, however, to quote figures directly from a report prepared in 1962 by the Automobile Club of Southern California (39). Table 8 summarizes the results of measurements of trip time and average speeds over a large number of routes in 1957, 1960, and 1962. Average speeds rose from 24 to 26 to 30.5 mph; average travel times declined from 51 to 46 to 41 min. During this period motor vehicle registrations in Los Angeles County increased from 3.0 to 3.6 million.

TABLE 8

AVERAGE SPEEDS AND TRAVEL TIMES IN LOS ANGELES[1] METROPOLITAN AREA, 1957, 1960, AND 1962

| Year | Avg. Speed (mph) | | Avg. Travel Time (min) | Regis. Veh. in Los Angeles County |
|---|---|---|---|---|
| | Overall | Range | | |
| 1957 | 24 | 20-33 | 51 | 3,010,000 |
| 1960 | 26 | 19-42 | 46 | 3,350,000 |
| 1962 | 30.5 | 22-42 | 41 | 3,575,000[2] |

[1]Source: "Peak-Hour Driving Study, Metropolitan Los Angeles." Automobile Club of Southern California, p. 2 (1962).
[2]Estimated.

A closer glimpse of the Los Angeles experience is afforded by Table 9, which gives a comparison of peak-hour travel times and average speeds in 1957, 1960, and 1962, on trips from Adams Boulevard and Figueroa Street to 16 different places in the Los Angeles area. For two of the places only 1962 data are given. Of the remaining 14, all but one show a decrease in travel time in 1962 from the 1957 value, and all but two show improvement in 1962 over 1960. For some routes the changes are small, but for others, such as the trips to Glendale, Long Beach, and Woodland Hills, the improvement is striking, probably reflecting the results of freeway openings.

Although the 1962 study concentrated on peak-hour travel, comparisons with trip characteristics of earlier years were more readily available for off-peak hours. Table 10 gives travel-time values for trips made from 7th and Broadway, Los Angeles, to 14 places during the period between 9:30 a.m. and 3:30 p.m. in the years 1936, 1957, and 1960. The progress over the years in reduction of travel time is quite evident. Reductions ranging from 20 to 50 percent between 1936 and 1960 were found on all these trips. Reductions between 1957 and 1960 were relatively small but occurred on all but two of the trips.

Table 11, taken from a 1962 report of the Chicago Motor Club (40, pp. 10-12 and Appendix Tables 9 and 10) shows that progress along the same line has been made in Chicago. The table contains a list of trip times measured before and after the opening of the Northwest Expressway on three arterial routes alternative to the expressway. There were significant reductions in travel time on all of these trips.

The sense of these findings is that, despite the widespread notion that urban traffic conditions are worsening, they are in reality improving with the progress of the Interstate System and other freeway programs. Improvements in traffic control without major capital outlays have also increased the capacity of arterial streets.

TABLE 9

PEAK-HOUR TRAVEL TIMES AND DRIVING SPEEDS IN METROPOLITAN LOS ANGELES,[1] 1957, 1960, AND 1962

| From Adams Boulevard and Figueroa Street to-- | Distance (mi) | Peak-Hour Travel Time (min) | | | Peak-Hour Driving Speed (mph) | | |
|---|---|---|---|---|---|---|---|
| | | 1957 | 1960 | 1962 | 1957 | 1960 | 1962 |
| Bellflower | 18.5 | - | - | 48 | - | - | 23 |
| Buena Park | 21.9 | 52 | 46 | 46 | 27 | 31 | 31 |
| Duarte | 24.9 | 54 | 54 | 51 | 28 | 28 | 30 |
| East Whitter | 19.9 | - | - | 44 | - | - | 27 |
| Glendale | 12.5 | 36 | 38 | 23 | 20 | 19 | 31 |
| La Habra | 23.0 | 62 | 69 | 52 | 22 | 20 | 27 |
| Long Beach | 25.2 | 65 | 41 | 36 | 23 | 37 | 42 |
| Pacific Palisades | 22.1 | 54 | 54 | 48 | 22 | 22 | 25 |
| Playa Del Rey | 12.0 | 32 | 32 | 29 | 22 | 22 | 24 |
| San Fernando | 27.7 | 51 | 50 | 40 | 29 | 30 | 38 |
| Van Nuys | 21.3 | - | - | 50 | - | - | 26 |
| Venice | 11.7 | 29 | 29 | 29 | 22 | 22 | 22 |
| West Covina | 23.8 | 47 | 47 | 42 | 30 | 30 | 34 |
| Whittier | 22.6 | 58 | 58 | 54 | 23 | 23 | 25 |
| Wilmington | 17.1 | 34 | 27 | 26 | 33 | 42 | 40 |
| Woodland Hills | 27.5 | 72 | 47 | 45 | 22 | 33 | 35 |

[1]Source: "Peak-Hour Driving Study, Metropolitan Los Angeles." Automobile Club of Southern California, p. 7 (1962).

Research in Traffic Guidance and Control.—Although the prospects for improvement in urban traffic conditions are bright, constant vigilance and the steady advancement of research are necessary in order to avoid retrogression under the pressure of metropolitan growth and expansion. Two major problem areas command attention: (1) That of conserving the capacity of the freeways and protecting them from crippling overloads;

TABLE 10

OFF-PEAK[1] TRAVEL TIMES IN METROPOLITAN LOS ANGELES,[2] 1936, 1957, AND 1960

| From 7th and Broadway, Los Angeles, to-- | Travel Time (min) | | |
|---|---|---|---|
| | 1936 | 1957 | 1960 |
| San Pedro | 48 | 42 | 35 |
| Wilmington | 39 | 36 | 29 |
| Bell | 25 | 22 | 20 |
| Downey | 33 | 25 | 24 |
| Norwalk | 37 | 27 | 26 |
| Hollywood | 23 | 17 | 16 |
| Universal City | 32 | 20 | 16 |
| Van Nuys | 45 | 39 | 28 |
| South Pasadena | 26 | 15 | 14 |
| Monterey Park | 25 | 21 | 18 |
| Pasadena | 31 | 21 | 18 |
| San Marino | 30 | 22 | 22 |
| Sierra Madre | 40 | 34 | 34 |
| El Monte | 31 | 26 | 24 |

[1]Between 9:30 a.m. and 3:30 p.m.
[2]Source: "Peak-Hour Driving Study, Metropolitan Los Angeles." Automobile Club of Southern California, p. 12 (1962).

TABLE 11

SUMMARY OF AVERAGE TRAVEL TIMES DURING RUSH HOURS ON ALTERNATE ROUTES BEFORE AND AFTER OPENING OF NORTHWEST EXPRESSWAY IN CHICAGO

| Trip | Average Travel Time (min) | |
|---|---|---|
| | Before | After |
| ROUTE 1 | | |
| From Lincoln and Cicero: | | |
| To Lincoln and Peterson | 7:35 | 6:40 |
| To Hollywood and Sheridan | 19:23 | 14:25 |
| To Lake Shore and Ohio | 33:08 | 24:15 |
| From Lake Shore and Ohio: | | |
| To Lake Shore and Sheridan | 12:00 | 9:35 |
| To Lincoln and Peterson | 24:00 | 18:10 |
| To Lincoln and Cicero | 32:00 | 24:35 |
| ROUTE 2 | | |
| From Foster and Cicero: | | |
| To Lincoln and Foster | 10:05 | 6:53 |
| To Sheridan and Foster | 17:15 | 11:50 |
| To Lake Shore and Ohio | 29:05 | 21:27 |
| From Lake Shore and Ohio: | | |
| To Lincoln and Foster | 20:45 | 16:41 |
| To Cicero and Foster | 28:55 | 24:05 |
| ROUTE 3 | | |
| From Elston and Cicero: | | |
| To Elston and North | 24:00 | 19:03 |
| From Elston and North: | | |
| To Cicero and Elston | 36:50 | 16:45 |

and (2) that of increasing the capacity of arterial and feeder streets. The focal points are those of intersecting or merging traffic—the interchange ramps of the freeway and the grade intersections of city streets. The resources of electronic computers and other modern research tools are being currently applied in a vigorous campaign on three fronts, those of traffic surveillance, traffic simulation, and traffic control. An able treatment of this subject is given in a recent paper by Baker (41).

Two projects that have been in operation for several years combine traffic surveillance and the amassing of data on freeway performance with actual traffic control. One is the Detroit Freeway Television Surveillance Project, of which Baker states: "The 14 television cameras, monitors, traffic sensing, analog computer equipment, and display system give the operators full control of all six freeway lanes during both normal, peak-hour, and emergency situations. Ramp entrance control signs have now been installed to close ramps for short periods during peak traffic in order to relieve observed congestion on the freeway." (41, p. 3). The other project, in place of television, utilizes ultrasonic detectors to sense the volume of traffic and measure average speeds along a 5-mi section of the Congress Street Expressway in Chicago. In Toronto, six years of preliminary study and a pilot traffic control project have culminated in the recent installation of a large-scale electronic computer to be used in actual time traffic control.

On the $7\frac{1}{2}$-mi, 12-lane Seattle Freeway a remote control system will be included as an integrally designed part of the highway. The plan for use of the surveillance control system to reverse flow in the four center lanes has eliminated the need for four additional lanes.

Numerous other important research projects involving simulation or surveillance have been completed or are now in progress. Among them may be mentioned a large-scale simulation covering 77 intersections in the District of Columbia designed to study various signal timing plans with the objective of minimizing total delay, and an application of simulation to the study of traffic on two-lane roadways undertaken at North Carolina State College.

Of broader import is the problem of insuring the protection of the metropolitan transport system as a whole from serious overloading. A single freeway can be protected by closing ramps, but how can the entire freeway-street network, or better, the freeway-street-transit complex, be protected? This is a problem in the total planning of the metropolitan area, its governmental organization and land uses as well as

its transportation system. It is a problem that must command the services of architects, geographers, political scientists, and sociologists, as well as planners, engineers, and economists.

It is plain, as previously stated, that the major problems in urban highway transportation are structural rather than financial. The decisions—as, for example, the extent of sharing, by freeway and rapid transit, of the traffic within a corridor—must be made on other than fiscal grounds. In this situation the role of congestion tolls is problematical. It may be that the problem of financing could be eased somewhat by revenues derived from some form of municipal or metropolitan-area user taxation. On the other hand, the economic orthodoxy of marginal-cost pricing is no great selling point if ample financing is available through the use of Federal and State road-user taxes. Furthermore, with congestion tolls as with miracle drugs, it is necessary to be watchful of the side effects.

## Income Effects

Beckman, McGuire, and Winston (19, p. 83), in discussing the meaning of consumers' surplus as a measure of user benefits, express the following admonition:

> All of this is not to say that the consumers' surplus would be easy to measure in practice, but rather that it is adequate from a conceptual point of view. However, mention should be made again of an implicit assumption on which its applicability rests, namely that there should be no effects on income which would render the costs saved at various levels of spending of unequal (per unit) value to the road users.

Questions of income effects, of the marginal utility of income, and the difference between money income and real income have always plagued the subject of welfare economics, tending to increase the uncertainty of whether individual satisfactions can be accumulated to mass totals of utility, benefits, consumers' surplus, or what not. Little (4, pp. 10-11) discusses some of these logical difficulties:

> There is a final necessary condition for achieving the maximum possible happiness, which is that the marginal unit of money must yield the same satisfaction to everyone. If this condition is not fulfilled, then happiness can be increased by taking money income away from one man and giving it to another. If we assume a law of diminishing marginal utility of income, this implies than an equalitarian distribution of income will yield the most satisfaction. But there is a trap here. Do we mean to assume that the marginal utility of money decreases as money income increases, or as real income increases?

It was noted earlier that Coase (7) objected to the income redistribution that would occur if the customers of decreasing-cost industries were subsidized at the expense of the customers of increasing-cost industries. In the case of congestion tolls the field is reversed, in that anticipated surpluses are coveted by some advocates (32, pp. 14-15) as subsidies to rapid transit lines. This prospective action is defended on the ground that the patrons of transit lines are, on the average, on a lower income level than motorists. This is probably true; but if a subsidy of rapid transit is in the interest of the general welfare, then the general tax base, resting on the wealth of the community, is a more appropriate source for the subsidy. This is also true if a State or Federal subsidy is contemplated.

In the great metropolitan areas where rapid transit lines exist or are thought feasible, the densest aggregations of people are found in the residential sections surrounding the central city and its major satellites. These close-in residents are rather well served by existing transit lines, whether surface or subway, although many of them group in car clubs and otherwise make use of automobile transportation. Although this group would benefit if fares were reduced, the impact of the scheme on commuters

by auto would be that of a one-two punch: those undaunted by congestion tolls would pay the subsidy; the craven-hearted would pay the fare.

It is generally agreed that there is a wide variance in the unit values people place on time savings, or on comfort and convenience. Mohring's calculations (20, p. 20) found the standard deviation of the unit value of time to be of the same order of magnitude as the value itself. The effect of the toll, therefore—and this also is widely recognized—is to sort out the prospective users of the tollway, rejecting those to whom the trip is not worth the price. Although there are numerous reasons for a given person to be unwilling to pay a toll at a given time, there can be no doubt that income status is the principal one, particularly in the case of a toll to be paid daily.

In the ordinary case of a toll road, bridge, or tunnel a marked advantage is to be gained by paying the toll. In the case of congestion tolls, if imposed according to the theory underlying them, the toll would be highest on the streets where, and at the times when, the congestion is greatest. The objective is to eliminate the congestion by forcing those unable or unwilling to pay the toll off the streets and on to another transportation mode, presumably subsidized by those electing to pay the toll. In the somewhat unlovely parlance of the economists, the well-heeled motorists are to "bribe" their less fortunate brethen to leave them in untrammeled possession of the arterial streets.

It must be acknowledged at once that all trip costs—user taxes, running costs, time costs, etc.—are parts of a price that some will not or cannot pay, that in this world of wages and prices some will have more to go on than others. Even so, congestion tolls as proposed are a new and drastic increase in trip costs, aimed directly at the lower income groups among motorists. They are to be imposed in accordance with a theorem of welfare economics to which Beckman's quoted admonition and Little's strictures apply. They nullify the phrase "other things being equal," for other things are not equal when there are significant income effects.

## Business Effects

The effect on various business interests of a proposed government action is a matter for delicate treatment. The decision to adopt or reject cannot hinge on whether one business group will gain or another lose. These facts are not immaterial, however. For one thing, the business gains and losses are a part of the complex of benefits and costs, whether or not they fit into the model. For another, the potential winners and losers hold cards in the game. It is a fact of economic life, of political economy, that those who have economic power exert it.

The Winners.—If one could accept the beguiling picture of a freeway system financed by congestion tolls on arterial streets, one would congratulate the motor vehicle user as the big winner. But this seems too easy, too much like winning the Irish sweepstakes, to be credible. A more likely winner in this unlikely game is public transit. Not necessarily existing transit, because a rapid transit system subsidized by congestion tolls would absorb at least part of the patronage of surface lines. Then there are the industries that would supply equipment and motive power to the transit lines. And there is the enterpriser who would equip each urban vehicle with the electronic device that would meter its congestion toll. There are indeed opportunities for maximization of benefits.

The Benefits of Toll Charges.—In most schemes to enact congestion charges the proposition of a system of urban toll facilities is offered as a "second best" solution, in view of the untested status of the electronic tax collector. Because urban toll collecting systems do exist—some of them highly solvent, others not doing so well—it is natural that extension of the practice, both in metropolitan areas where tolls are charged and in those where they are not found, should be regarded as a promising prospect. As a result of a successful campaign in this direction, one might look forward to the day when each great metropolitan area would be girdled by a not entirely invisible wall of toll charges. Such a situation would be reminiscent of the medieval charge called the "octroi" which was levied against visitors attempting to transport goods into a walled city for sale. There is, of course, Manhattan Island, a sort of

moated grange to which it is difficult to find entrance without paying tribute to the benevolent but well-heeled bondholders of its encircling toll facilities.

Because the intent to collect tolls implies the construction of toll expressways, or at least crossing facilities, the motor vehicle user might be expected to greet the prospect with glee, were it not for the fact that he is expected to share his benefits rather generously with the investors in tax-exempt securities, who have proved themselves to be no amateurs at the benefit-maximizing game. Table 12, compiled from information in the McCallum report (29, pp. 35-42), gives a brief analysis of the financing of five of the most recent large toll-revenue enterprises, and compares revenue-bond financing with the estimated costs of general-obligation bond financing (limited-obligation in Maryland) at interest rates at which each of the States issued highway bonds in the same or a very recent year.

The contrasts are striking. In issuing State highway bonds it is seldom if ever necessary to have their value exceed the capital outlays to be financed. In each of the five cases described in Table 12 the par value of the bonds issued far exceeded project costs in right-of-way, construction, and related expenses. The ratios of bonds issued to project costs vary from 1.15 for the Northeastern Expressway in Maryland to 1.44 for the Chesapeake Bay Bridge and Tunnel Commission project in Virginia.

McCallum's comparisons deal with the total cost of financing to the date of final maturity. The ratio of financing cost (including interest, redemption, and other charges) to project cost varies from 2.15 for the Massachusetts Turnpike Extension to 3.48 for the Chesapeake Bay Project in Virginia. In contrast, the corresponding ratio for the estimated general- and limited-obligation bond financing varies from 1.28 to 1.57 in four of the five States. No comparison is available for Virginia, as that State has no history of State highway bond issues. For the other four projects the ratio of revenue-bond financing costs to the estimated costs of general- or limited-obligation bond financing varies from 1.59 to 1.79.

The most direct comparison is that between the net interest rates, inasmuch as the higher rate paid on revenue-bond issues represents the premium price paid to the

TABLE 12

COMPARISON OF RECENT TOLL-REVENUE BOND FINANCING WITH ESTIMATED GENERAL-OBLIGATION BOND ISSUES AT RATES OF SUCH ISSUES BY THE SAME STATES IN RECENT YEARS[1]

| Item | Massachusetts Turnpike, Boston Extension | Kentucky Turnpike Authority | Delaware Turnpike and Northeastern Expressway | | Chesapeake Bay Bridge and Tunnel Commission |
|---|---|---|---|---|---|
| | | | Delaware | Maryland | |
| Project costs | $152,000,000 | $130,569,950 | $23,957,250 | $ 64,200,000 | $139,200,000 |
| Revenue bond issues: | | | | | |
| Year of issue | 1962 | 1961 | 1962 | 1962 | 1960 |
| Net interest cost or interest rate | 4.48 and 5.00 | 4.86 and 4.928 | 4.1875 | 4.1875 | 5.61766 |
| Par value of issues | 180,000,000 | 157,000,000 | 28,000,000 | 74,000,000 | 200,000,000 |
| Interest and other financing | 146,863,000 | 169,091,631 | 27,474,000 | 72,419,000 | 283,760,794 |
| Total cost of financing | 326,863,000 | 326,091,631 | 55,474,000 | 146,419,000 | 483,760,794 |
| Ratio of financing to project cost | 2.15 | 2.50 | 2.32 | 2.28 | 3.48 |
| Estimate of general-obligation bond financing at rates of State issues in same years | - | - | - | -[2] | -[3] |
| Interest rate, percent | 3.10 | 3.60 | 3.20 | 3.50 | - |
| Par value of issues | 152,000,000 | 130,000,000 | 24,000,000 | 64,000,000 | - |
| Interest | 51,615,000 | 74,800,000 | 8,064,000 | 17,920,000 | - |
| Total cost of financing | 203,615,000 | 204,800,000 | 32,064,000 | 81,920,000 | - |
| Ratio of financing to project cost | 1.34 | 1.57 | 1.34 | 1.28 | - |
| Ratio of revenue-bond financing cost to general-obligation bond financing cost | 1.61 | 1.59 | 1.73 | 1.79 | - |

[1]Source: "Highway Bond Financing: An Analysis, 1950-1962." William R. McCallum, U. S. Department of Commerce, Bureau of Public Roads (1963).

[2]It has been the practice in recent years for the State of Maryland to issue limited-obligation highway bonds secured by road-user tax revenues.

[3]There is no history of State highway bond financing in Virginia to afford a basis of comparison.

investor for his risk in buying securities not backed by the full faith and credit of the State or the assurance of its sturdy user-tax revenue structure. In calculating the following ratios the arithmetic mean was used in the two cases where two rates of revenue-bond interest are shown:

| Project | Ratio of Net Interest Rates, Revenue-Bond Issue to Estimated General- or Limited-Obligation Bond Issue |
|---|---|
| Massachusetts Turnpike Extension | 1.53 |
| Kentucky Turnpike Authority | 1.36 |
| Delaware Turnpike | 1.31 |
| Northeastern Expressway, Maryland | 1.20 |

The relatively low value of the ratio in the Maryland case is attributable chiefly to the fact that a limited-obligation rather than a general-obligation bond issue is used in the comparison. If it were to be assumed that Virginia would be equally able to issue State highway bonds at 3.5 percent interest, the ratio for the Chesapeake Bay Bridge and Tunnel Commission financing would be 1.61. Such are the surcharges a State—and the user—pays for the privilege of floating toll-revenue securities.

The Losers.—The widespread adoption of congestion tolls in such magnitude as actually to discourage the use of motor vehicles in metropolitan areas would have an adverse effect on motor vehicle manufacturers, tire manufacturers, the petroleum industry, and the corresponding distributive businesses. Consideration of this point can lead to a variety of conclusions. People in the industry would naturally resist any attempt to limit the use of their products. The owners of automobiles and commercial vehicles would be resentful of imposts materially above those they are accustomed to paying. If the outcome were such as to cause a drastic curtailment of urban freeway programs, highway contractors and the suppliers of construction materials and equipment would be affected to some degree. The vast structure of employment in the highway-motor-vehicle industry would suffer a disturbance, the magnitude of which would depend on whether the anti-motor-vehicle distemper, now rather closely confined, became epidemic.

It has been held that the question of effects on the motor vehicle industry is not germane; that congestion tolls should be imposed because they are necessary in order for the motor vehicle to pay its due share of highway costs. If the charges were based on the public outlays required to defray the costs of the freeway program, they could be accepted calmly in the realization that the benefits would equal and probably exceed the costs. But the fact is that freeway programs are being financed at the present rates of Federal and State road-user taxes, and at the most, only moderate increases are in prospect. Congestion tolls are justified on the ground that marginal-cost pricing, based on time-delay and other costs incurred by the users, maximize benefits. In this context side effects, such as benefits or disbenefits to business and employment, may with reason be regarded as a part of the total benefit-cost equation.

On the other hand, it is possible to take a detached viewpoint and ask whether there are too many motor vehicles or whether their number is increasing too rapidly, whether too much time and money are being spent for motor vehicle transportation, whether considerations of frugality do not dictate seeking the least expensive forms of transportation from here to there. From this angle congestion tolls are advanced as a means of promoting the optimum utilization of resources in the realm of urban transportation.

This viewpoint can be generalized to an attitude on nationwide and worldwide affairs. Perhaps resources are being wasted; perhaps we are living too well; perhaps if we lived less well we could be of more assistance to the underdeveloped countries. In other words, if the American standard of living were to be lowered, perhaps stand-

ards could be raised elsewhere. The trouble with this notion is the simple fact that a regime of austerity at home is quite unlikely to yield a surplus for export abroad. Only by producing abundance for ourselves can abundance be helped to appear in other places.

These observations do not do away with the vexing question of whether too much is being spent on motor vehicle transportation and too little on some other things. The same question applies to the entire spectrum of goods and services in both public and private economies. In the particular field of urban transportation a proposed action, such as the creation of a system of congestion tolls, can only be justified if it improves the quality and increases the availability of transportation. A policy aimed at cutting down the use of motor vehicles in the urban area seems unlikely to accomplish either purpose.

## Community Effects

The urban community is a far-spreading and complex entity, often embracing several counties as well as the central city. The nature of the governmental structure makes planning difficult and consistent decisions even harder to come by. The transportation and communication systems are the means by which the city's life and movement become effective in production, distribution, education, religion, recreation, social and family activity. Decisions made about its transportation system should be decisions of and for the whole community. They should not attempt to stop the clock. They should not attempt to pour the developing metropolis into a rigid and undeviating plan. They should be in harmony with the observed long-term trends of regional growth.

Congestion Tolls and the City Center. —The objective of preserving the best values of the city center—commercial, governmental, cultural, scientific—is one that, if conceived in realism and not in nostalgia or hysteria, commands almost unanimous acclaim. This objective will not be served by transportation charges that are coercive in character and go against the grain of the urban, suburban, and exurban residents. Motorists have choices that go beyond the question of whether or not they use their automobiles in driving to the central business district. They may be able to look elsewhere for employment opportunities and they certainly can look elsewhere for places to do their shopping and other family business. The persistent trend for more rapid growth, in business and employment, of the outer rings of metropolitan areas, in comparison with the slower growth (and sometimes decline) of the central city, has been observed and depicted in many studies. Meyer, Kain, and Wohl (38, pp. 1-15) discuss this trend and cite many of the reports that give evidence of its persistence.

It is quite unlikely that either the trend of urban residents to move to the suburbs or the trend of business and industry to seek outlying locations will be reversed by even the most strenuous efforts to block them. Indeed it is apparent that the best chance of preserving the commercial, governmental, and cultural values of the city center lies in keeping open and improving the channels of communication, both transit-oriented and highway-oriented, rather than in efforts to favor one against the other. This point was made by Goldstein, Kanwit, and Rapp in their comments on the Walters article (26) quoted earlier in this paper.

Moses (42, pp. 7-8), discusses the question of the effects of metropolitan development, in the following terms:

> The efficiency argument has a great deal of force and as an economist I accept it. However, city planners, municipal officials, and public administrators whose real concern is not traffic congestion and the inefficient use of highway capacity—viewed as a resource—but the economic future of our mature, central cities, should pause before accepting it.
>
> The assumption most often made in studies that deal with traffic problems is that people will shift to public transportation for the downtown work trip if the cost of automobile commuting is increased sufficiently. There is a third alternative. Substantial

> increases in the cost of downtown commuting could solve the traffic congestion problem by encouraging a faster movement of manufacturing and business establishments from the core area of the city to suburban areas, or even to the newer, less-well-developed portions of the country.
>
> In economists' language, all of us have been proceeding as if the demand for downtown trips is perfectly inelastic and choice restricted to the various means of getting there. This is incorrect. Transport costs are a significant factor in determining where within a metropolitan area economic growth will take place. If the cost of getting to the downtown area is greatly increased, there is a strong possibility that the core area's traffic problem will be solved by reducing the number of people who work there.
>
> Changes in price are not the only method by which diversion may be carried out. Investments that reduce travel times and the disutility of travel by the alternative modes might prove effective.

It is rather interesting that some of the advocates of congestion tolls cite them as a means of accomplishing the objective of moving business and employment out of the city center. Roth and Thomson (43), advocate what are, in effect, congestion tolls and some form of electronic device for their measurement and recording. In discussing the effects of such a congestion toll system the authors speak hopefully of "... a tendency for occupations associated with large road requirements to leave city centers and to make way for occupations requiring less .... "

Thinking Regionally. —The image created by the congestion-toll proposal is that of the beleaguered central city protecting itself from invasion by the residents of its outlying areas, the suburbs, and the surrounding countryside, by means of a system of charges becoming ever more mountainous as the inner citadel is approached. The unhappy analogy with a medieval walled town was previously cited. It is true that the outward movement of people and business has produced dislocations in the tax base and in the provision of services such that the commuter from the outer areas often seems to derive an unfair advantage. The multiplicity of local governments, often of two or more States, further complicates the situation. It is unlikely that the alpine system of mounting charges is the ideal remedy. The object is for the city center to attract, not repel, invaders.

It should be obvious that these difficulties are to be solved, if at all, by an approach to regional government, or at least regional action based on genuine regional planning. Beginnings have been made in a few metropolitan regions, of which the Metro experiment in the Miami area (44) is the best known. The problem is difficult in an interstate metropolitan region, such as the tri-State New York City area or the District of Columbia-Maryland-Virginia complex. The most progress, perhaps, has been made in the metropolitan transportation studies, past and current, in these great areas. The transportation studies point the way toward areawide solutions. Fortunately, Federal and State programs will provide most if not all of the funds for the needed freeways and major arterials. If more highway funds are needed, regional user taxes, preferably at moderate rates, are not unthinkable. They certainly would be preferable to, and probably more lucrative than, congestion tolls levied on the last few miles of the suburb-to-city trip. Solution of the governmental problems of metropolitan regional taxation (user or other) should not be beyond the reach of American ingenuity, even in an interstate area.

The role of public transit is a major element of the regional transportation plan, and should be solved integrally with the highway plan. If subsidies are needed, regional taxation again seems to be indicated, but in this instance not aimed at the motor vehicle user as such.

## SUMMARY

1. In the first part of this report the elements of marginal-cost theory were presented and the views of a number of economists, including Little and Samuelson,

about the sanctity of the rule of marginal-cost pricing were discussed. In view of the skepticism of these experts and the cogency of the reasoning and evidence they presented, it was concluded that no planning official or public authority is obligated, in theory or in equity, to adopt marginal-cost pricing of a public service, and that schemes for this form of pricing should be subjected to the tests of popular acceptability, of soundness from the standpoint of public finance, of consistency with observed trends in the development of the affected area, and of conformity with the objectives of long-range regional plans.

2. The second section discussed the formulations of economists who have developed the theory by which the marginal cost of congestion determines the price at which user taxes or tolls are to be set. Particular attention was given to the work of Mohring and Strotz, whose models, contrary to the practice in earlier formulations, include highway costs as terms in the equations.

Acknowledging the reality of congestion costs, comments on Mohring's treatment stressed the basic incongruity, to motor vehicle users, of being taxed for the costs they cause themselves and each other. Strotz's formulations elicited the observation that, although the interdependence of highways with other economic activity was written into the model, the very form of the equations, designed for a simple optimization procedure, insured that the implicitness would disappear in the partial derivative.

3. In the third section the implications of congestion tolls were considered. It was first suggested that a proper model to represent highways and highway finance in a real world would be a dynamic one, hitched to the chariot of time, that would take note of this year's taxes building next year's highways, of the growth of traffic and the expansion of the highway plant, of long-range plans and programs, and of the effects over time of the decisions that might be made. And it was hinted that in such a model marginal-cost pricing would perhaps not play a crucial role.

4. Next the current status and characteristics of urban highway financing were reviewed. It was found that expenditures and annual costs per mile of travel are lower in urban than in rural areas, with the exception that urban freeways seem to cost somewhat more per vehicle-mile than their rural counterparts. It was further found that, although local nonuser taxes still make a substantial contribution to the support of ordinary city streets, Federal and State road-user tax revenues are dominant in urban highway finance, particularly in the construction of expressways and other major connections of Federal-aid and State highways. In the analysis of 1960 revenues, expenditures, and earnings of user taxes and tolls in 46 Standard Metropolitan Statistical Areas it was found that (a) earnings were far in excess of the user revenues applied to roads and streets in these urban places and (b) the aggregate user earnings in these 46 SMSA's exceeded the aggregate expenditures on roads and streets by 11 percent. From this review it was concluded that in view of the adequacy of present rural and urban highway financing, through a combination of Federal and State user revenues with local funds derived from both user and nonuser sources, congestion tolls are not needed as a supplementary source of urban highway revenues.

5. Some of the characteristics of urban travel were next examined, including (a) the surprisingly small proportions of all urban trips that are made to or from the downtown area; (b) the fact that a majority of trips entering the central business districts of metropolitan areas have destinations elsewhere, a situation that can be corrected by the provision of an inner beltway; (c) the characteristics of peak-hour traffic on both freeways and rapid-transit lines; (d) parking costs as an element in total trip costs; (e) an examination of time savings in relation to a typical commuter trip, leading to the inference that the levy of congestion tolls on the last few miles of a trip is no substitute for a user-tax-supported freeway; (f) the introduction of evidence showing the reduction of trip travel times and increase of average speeds resulting from the construction of expressways and the improvement of traffic control on arterial streets; and (g) a discussion of current research in traffic surveillance, simulation, and control on both freeways and arterial streets. This review led to the conclusion that the problems of urban transportation are mainly structural, demanding the cooperation of architects, engineers, sociologists, planners, and many others; and that the congestion-toll proposition has little to offer toward their solution.

6. Authorities were quoted to the effect that the validity of theorems involving the maximization of benefits is contingent upon the absence of adverse income effects—e.g., in Little's words "... that the marginal unit of money must yield the same satisfaction to everyone." Two kinds of income effect were pointed out: (1) The subsidy of transit users by motor vehicle users often advocated as a part of the congestion-toll proposition; and (2) the discrimination against low-income motor vehicle users inherent in congestion tolls.

7. Effects on business—favorable to rapid transit, to suppliers of rapid-transit equipment and power, to purveyors of electronic congestion-tax metering devices, and to investors in tax-exempt toll-revenue bonds; adverse to motor vehicle users, manufacturers, distributors, and suppliers—were cited as elements in the complex of benefits and costs that are not cared for in the congestion-toll formulations.

8. In discussing community effects the point was made that the imposition of congestion tolls, rather than conserving the central business district, might well produce the opposite effect by inducing motor vehicle commuters to seek employment elsewhere and causing downtown businesses to move to outlying and suburban locations. It was further urged that the problems of metropolitan regions, whether structural or financial, be attacked and solved on a regional basis.

In view of this series of adverse findings it is concluded that congestion tolls do not offer great promise as a means of improving the conditions of urban transportation.

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# Principles of Urban Transportation Pricing

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•THIS PAPER discusses some of the fundamental economic principles that underly the pricing of urban passenger transportation services. This is done primarily in the context of private automobile transportation, although many of these principles relate as well to the problems of mass transit. Throughout, abstracts are drawn from all those practical problems, which are admittedly both important and intractable, that arise when one attempts to implement any general set of guidelines governing the appropriate pricing of transportation services, especially the difficulties of measuring the appropriate magnitudes for tolls and roadway expenditures as well as the difficulties of collecting tolls that should in principle vary with time of day and the particular point of travel. Thus, the subject is restricted to what might be called the "pure" theory of transportation pricing.

In developing a pure theory, one abstracts from a great variety of realistic detail. For that reason, the current analysis invokes what would ordinarily be called "models" of transportation pricing situations, a model being a highly simplified representation of the reality with which one wants to deal. But, because the particular artificial problems chosen for consideration are not purported to capture even all of the more important aspects of reality, there has been a reluctance here to write of "models." The artificial cases considered are each selected to illuminate some particular aspect of real-life problems with the purpose of illustrating some single principle. For this reason, reference has been made elsewhere (1) not to "models," but to "parables." This latter term suggests more accurately the concern mainly to tell some simple stories, involving a good deal of make-believe, each of which contains some "moral" regarding transportation pricing. Systematic economic analysis of urban transportation problems seems not yet to have advanced beyond the level of what is essentially a paradigmatic treatment, and one must at present be content to improve the artful exercise of the urban planner's judgment by such useful insights as can be gotten from considering various grossly simplified situations.

A pricing mechanism in urban transportation, as in other parts of the economy, is called upon to solve several different problems at the same time, and much confusion about pricing principles arises when those problems cannot all be solved by the same price structure. One problem (the investment problem) is to determine the kinds and amounts of resources that society should fix in particular uses for fairly long periods of time or, more specifically, to determine how much land, concrete, etc., should be invested in a given road network. Once these decisions about road locations, road widths, interchanges, bridges, etc., have been made, there then arises the further problem (the rationing problem) of how they should be used. Who should make what trips and when? The main reason for not permitting unrestricted and unlimited use of an existing road network is only in part the increased wear and tear on the roads themselves from greater use, but more significantly the problem of congestion. The essence of the congestion problem is that each individual's use of a road imposes certain costs or disadvantages on others who use the road at the same time. These two problems, of appropriate investment and appropriate rationing of a given network among users, are interrelated in that the appropriate investment depends on how the network that is constructed will be used and the appropriate use depends on the fixed

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character of the existing network. Is there a set of prices (tolls) that will solve both of these related problems in a single stroke? A third problem (the income distribution problem) has to do with the relative importance for social decision-making of the many different individuals in the society. Are some to be allowed more travel than others or, more precisely, are the desires of some people to travel to be held in greater importance than the desires of others? Whenever a pricing system is used to solve the first two problems mentioned, it will affect what may generally be called the "distribution of income," or still more generally, "the distribution of satisfactions" among the various individuals in the economy. If one wishes to choose a pricing system so as to influence the distribution of satisfactions among different people, can the system then also be used to solve the problems of investment and of rationing? Is there a set of prices that can solve all three problems—investment, rationing, and income distribution—simultaneously?

In the private sector of the economy, investment resources are assumed to flow to those industries and uses where their expected earnings are above normal and to flow out of those industries and uses where the expected returns are negative or, at most, below normal. These forces are assumed to move the economy always in the direction of an equilibrium position where all fixed investments receive just the normal return; and it is demonstrated, under the conventional assumptions made by economists when analyzing policy problems, that in this equilibrium all capital goods would be put to the best possible use; that is, that it would not improve economic welfare to shift any resources from one industry to another. The earnings on capital, of course, depend on the structure of prices; not only the prices of goods and services that are produced at the end of the production line, but also on the prices of those services of production factors that enter as inputs in the production process. To rely on a profits or earnings motive to guide investment in the long run then requires a price system that will bring about this equality of returns throughout the economy. In short, the proper level of investment of fixed resources in any particular use must be expected at prevailing prices to just pay for itself, yielding just the normal return to the investors. If this same rule were applied to the pricing of highway use, the structure of tolls would need to be such that the appropriate expenditure incurred in constructing and maintaining the road network would just equal the sum of all toll receipts paid by all users on all roads. Indeed, this condition should be satisfied not simply for the entire network, but separately for each and every inch of highway construction. A price system for road use that does not lead to the "zero-profit" condition (where by profit is meant any return in excess of the normal return on capital) would seem to be other than optimal. If profits were positive, this would appear to be a signal that further investment is needed, and if profits were negative, a signal for reduced investment. If a set of prices exists so that there will be zero profits when just the right road network has been constructed, that set of prices will have solved the optimal investment problem.

Regarding the private sector, it is also thought that prices should be set so as to bring about an equality between the extra cost entailed in the production of a bit more of any commodity and the extra satisfaction that someone can gain by consuming that incremental amount of that commodity. The concept of cost that is relevant here relates ultimately to (a) the loss of satisfaction that the buyer of the incremental output must incur for having to accept slightly less of other things in order to make that incremental production possible. It also incorporates (b) any reductions in satisfaction imposed on others by virtue of the slight redeployment of resources that are involved in the shift of production that would occur. In the case of road use, it may be said that the extra satisfaction that a particular motorist derives from an additional trip (per unit time, for example, per year) on a given road must be just equal to (a) the loss of satisfaction he incurs by having his consumption of other goods and services reduced as may be necessary to divert resources for the increased upkeep of the road required by the greater wear and tear that his additional trip creates plus (b) the loss in satisfaction incurred by his fellow motorists because his additional use of the road increases the congestion that they experience and to which they object. When this delicate "balancing at the margin" is achieved throughout the society, it may be said

that the rationing problem has been solved. The question, therefore, is: "What set of prices, including road tolls, will induce people to travel on different routes with just that frequency so that this balancing at the margin is everywhere achieved? If there exists a set of prices that will do this, those prices may be regarded as optimal because they solve the rationing problem.

What is disconcerting is that the set of prices, including tolls, that may solve the rationing problem might be different from those that solve the investment problem. Now, one of the achievements of economic analysis is to show under what idealizing assumptions regarding the nature of people's preferences, the nature of technology, and the nature of the organization of firms within the industries of a free enterprise economy, the very same set of prices will happen to solve both problems at once.

Suppose a set of prices has been found for all commodities, including transportation services, so that both the investment and rationing problems are simultaneously solved. That set of prices will also dictate a distribution of income or welfare for all individuals in the economy: some will be poor, others will be rich. Some will consume little and others much. Is the distribution that results liked, or is it regarded as unfair or even as politically dangerous? Unless one is prepared to accept whatever distribution of income happens to result from the use of the price mechanism to solve the investment and rationing problems, he may prefer a distribution different from the one that actually ensues. It should be clear, therefore, that there is a very real danger that in asking for a single set of prices to solve all three of these problems the price system is being called upon to do more than it can.

There are easy ways in which the economic analyst can avoid the problem presented by considerations of an ethically appropriate distribution of income. One way is to suppose that any distribution of income is ethically as good as any other, so that the problem is essentially ignored. Another solution, differing only subtly from the first, is to suppose that there are both good and bad distributions of income but that whatever distribution is generated by a price system that solves the investment and rationing problem, is the best one. A third device for avoiding the problem is to assume that the distribution of income can be altered without tampering with the price mechanism. This is conceptually possible. One could imagine that there is a Robin Hood who will, every period of time, steal just the right amount of income from those who are thought to have too much and dole it out in just the right way to those who are thought to have too little. This must be done in such a sneaky fashion, however, that no one is ever aware that his earnings or expenditures will ever affect his treatment at the hands of Robin Hood. Otherwise, he has an incentive to behave differently (for example, to work more or less) in order to alter the way in which Robin Hood treats him. What Robin Hood in effect does is to impose a system of head (or flat) taxes and subsidies that may differ from person to person, that do not affect the terms on which anyone believes he can exchange one commodity for another or exchange labor for commodities, so as to bring about just that distribution of income that is desired. Such a system of head taxes and subsidies is not feasible, either politically or administratively; in reality, if it is wished to alter the distribution of income in the economy it must be done by interfering with the price mechanism. But, in a long (though much too honored) tradition, let it be supposed that Robin Hood can and will do one's bidding, or that head taxes and subsidies can always be imposed and collected in just such a way as to bring about any particular distribution of income that might be wanted. Thus, the remainder of this discussion, essentially abstracts from the demand placed on the price system to solve the distribution problem.

Suppose the same set of prices cannot solve both the investment and rationing problems. Then what is to be done? Part of the answer is that the problem of inconsistency between prices that solve the investment and those that solve the rationing problem simply does not arise except under special and uncommon circumstances. The main concern is with whether there are decreasing, constant, or increasing returns to scale in production with respect to some set of factors of productions. By decreasing returns, reference is made to the case where if the factors of production are increased in equal proportion, the amount of product yielded will be increased in a smaller proportion. Increasing returns to scale is the contrary case where product

increases in greater proportion than the given equal proportional increase in the factors of production. And constant returns to scale occurs when product increases in the same proportion in which the factors are increased. By "factors of production" is not meant absolutely everything that can effect output, but only those things that are economic goods, which means that it must be possible to identify them, to claim ownership rights in them, and to choose among alternative uses for them. It is because some things that effect production through the technology exist in limited supply and cannot be increased in equal proportion with other factors that there may be diminishing returns to scale. If there are influences present that operate negatively on the production process and cannot be removed, but do not themselves increase as the factors of production are increased, then there may be increasing returns to scale. Even if such impediments to production, however, can be identified and could be owned, no one will claim ownership rights in them. Fixed factors of production that contribute positively to the production process will generally be "owned" by somebody and that owner, if able to withhold those factors from a particular use, is able to command a certain return for letting them be used. This return is an "economic rent, " and will be included in the cost of production. But if there are fixed impediments to production, no one will claim to own them and, though from the social point of view they "earn" a negative rent, there will be no one willing to collect that negative rent, and so the socially appropriate deduction from other production costs accounted for by these impediments will not be deducted in the calculations of the private marketplace.

It is in this case of increasing returns, which can be interpreted as the case where there are present one or more impediments to production, that the solution to the rationing problem defines a set of prices at which profits will be negative. The solution to the rationing problem then yields prices that will not solve the investment problem. In this case, the standard answer is that government must subsidize investors, in effect collecting what may be regarded as the negative rents that no one in the private sector will voluntarily collect. The proceeds for these government outlays in subsidizing industries of increasing returns are in turn to be collected from the private sector in the form of head taxes, thus not interfering with the price mechanism used to solve the rationing problem.

It remains an open question whether the technology of urban highway transportation is such that government must collect negative rents (i.e., subsidize the road network). It is also an open question whether the technology of urban road transportation is such that, even if there are diminishing returns to scale, it is possible for private individuals to collect the positive rents whose payment, as a cost of production, reconciles the pricing solutions to the investment and rationing problems. These questions are examined in the parables studied (1) and reported on here.

The first and simplest of these parables considers a society with a fixed number of individuals, each of whom has a definite set of preferences among alternative combinations of (a) the number of round trips that he is able to make from Here to There and back again along a given road, per unit of time, the quantity of other goods that he is given to consume per unit time, and the degree of congestion that he encounters on the road while traveling. Other goods are represented by a single commodity, called "bread." It is assumed that the individual prefers more trips to fewer trips, other things being the same, and that there is a common measure of congestion that can be used in defining the preferences of different individuals. Other conventional assumptions about the nature of the preference structure of the individual are also made. But at this point, as in much of what follows, the reader can only be referred to the previous paper (1) for a more precise listing of the various assumptions employed. The production of the representative other commodity, bread, is assumed to occur under conditions of either constant or diminishing returns to scale, so that there are no serious problems there. The society, however, is assumed to have only a fixed quantity of productive services to use in each period of time and these must be allocated between two different uses: one to produce bread and the other to "produce" the road. The resources to be used in producing the road each period of time (say each year) would in fact be represented by both maintenance expenses and interest expenses on any capital expenditures that would occur irregularly over time. Though not descriptively realistic, it may be simplest to think of the road as something that

wears out and must be replaced each unit of time. This kind of abstraction does little harm because, in any case, only the long-run equilibrium (steady state) solution to the problem of the optimal road is being considered.

There must also be a production function reflecting the road technology, and this is a relationship defining the degree of congestion as a function of the annual expenditure of productive services on the road and of the total volume of traffic (that is, the total number of trips made on the road per unit time). It is also imagined that the flow of traffic, whatever its level may be, is at a steady rate, with no hourly or daily variations. This function may be expressed as

$$d = D(\Sigma_i t^i,\ E) \qquad (1)$$

in which d is the measure of congestion, E is the annual expenditure of resources on the road, and $\Sigma_i t^i$ is the sum over all individuals, i, of the number of trips made by these individuals, $t^i$, $i = 1, \ldots, I$.

Much will depend on the nature of this production function. One case arises if, when the annual expenditure, E, and the volume of traffic, $\Sigma_i t^i$, be increased in equal proportion, d remains the same. This is the case of constant returns to scale. If, however, an equal proportional increase in traffic and road expenditure increases d, this represents adverse returns to scale; and if that decreases d, favorable returns to scale. This may seem a bit different from the earlier classification of production functions into the categories of constant, decreasing, and increasing returns to scale because there the dependent variable, product, needed to increase in equal, lesser, or greater proportion than the factors of production, respectively. Here the categorization rests on whether d stays constant, increases at all, or diminishes. The conceptual difference is, however, more apparent than real. The three cases identified here could be restated as follows: if the quality of the product, d, remains the same, is it possible to achieve the same percentage increase in output, $\Sigma_i t^i$, as the increase in the input, E? If so, there are constant returns. The case of adverse returns, as previously defined, is the case where, to hold the quality of product, d, constant, the volume of output, $\Sigma_i t^i$, must be increased in lesser proportion than the increase in the input, E. Adverse returns therefore corresponds to the case of decreasing returns. By the same reasoning, the case of favorable returns corresponds to the standard case of increasing returns. (No attempt is made in this study to estimate whether constant, adverse, or favorable returns are more common in reality. A word of caution is advisable, however, against any quick presumption that favorable returns are the rule. It may be thought that this is the case because a two-lane road (in one direction) can carry more than twice the traffic of a one-lane road at the same speed. But the input, E, is not a measure of cost at constant prices; it is a measure of cost expressed in terms of foregone alternatives. Especially to the extent that land is an input in road construction, the widening of a road or the expansion within a given area of a road network entails adding land that may have increasingly greater value in alternative uses. This would work towards adverse returns to scale.)

The first question is: Suppose that the individual receives a fixed per-unit return for any of society's total factor services that he contributes to production per unit time, that he must pay a head tax or subsidy per unit time, and that he confronts a given unit price for bread and a given toll for each trip he makes on the road. How much bread will he want to buy and how many trips will he choose to make each unit of time in order that he maximizes his satisfaction as reflected by his preferences? Conditions giving the solution to this problem for each individual are then introduced as "behavior conditions" in the problem of deciding what is the proper toll and what is the proper expenditure on the road.

Subject to all these conditions, one then asks what requirements must be imposed on the prices, including the toll, and on the allocation of the productive services between producing the road and producing bread in order that it should not be possible,

through any change, to move any individual to a position he prefers more without having to move another individual to a position he prefers less. A situation of this sort, where it is impossible to benefit anyone without hurting someone else, will be referred to as a pareto optimum, and there will be many such optima depending on the distribution of income, which may reflect a judgment as to the relative importance of the levels of satisfaction achieved by different individuals. Different distributions of income would be achieved by different assignments of head taxes and subsidies.

In short, it is desired to know what conditions are necessary in order that a pareto optimum can result. For the case analyzed, the following conclusions can be drawn:

1. There does exist an optimal level of expenditure on the road, but this depends on the distribution of income that is chosen to be most suitable.

2a. There does not exist an optimal toll for the use of the road that is the same for all individuals, but tolls must differ from person to person.

2b. If the further simplification is introduced that the individual does not take account of the extent to which his own use of the road affects the congestion that he himself experiences (a simplification that seems not very objectionable), then there does exist an optimum toll that is the same for all individuals and all trips.

3. Under the simplification of 2b, this optimum toll is defined in terms of economic relationships that are measurable in principle though very difficult to measure in practice.

4. Continuing under this simplification, there is no apparent market mechanism that will provide a measure of what the optimal toll should be.

5. The optimal level of expenditure on the road should exceed optimal toll receipts by the amount $S/D_E$, where

$$S \equiv D_{\Sigma t} \Sigma_i t^i + D_E E \qquad (2)$$

and $D_{\Sigma t}$ and $D_E$ are the rates of increase in d with respect to increases in annual traffic volume and road expenditure, respectively (partial derivatives of $D(\Sigma_i t^i, E)$).

If there are favorable returns to scale, S will be negative and, because $D_E$ is negative, optimal road expenditures should exceed optimal toll receipts. The difference is a subsidy to be paid for the construction and maintenance of the road out of funds raised by head taxes. In the case of adverse returns to scale, S will be negative and the optimal expenditure on the road should fall short of optimal toll receipts, the excess of toll collections over road costs being returned to the public in the form of head subsidies. If $S = 0$, the road should be exactly self-financing out of toll collections.

The case of adverse returns to scale corresponds to diminishing returns in industrial production. If something is lost through the expansion of scale, this results from the presence of some fixity in the technological process. In the conventional theory of industrial production, this would be ascribed to the presence of fixed factors of production that earn an economic rent, which would be collected by their private owners. In the case of the optimal road problem, however, this fixity cannot be identified by a factor of production for whose use a charge will be made over and beyond the cost of road construction and maintenance; therefore, the road should be operated at a "profit," with toll receipts exceeding road expenditure. In the opposite case of favorable returns to scale, there is some impediment in the production process that is increasingly overcome as road expenditure increases. With an equal percentage increase in traffic, it would be found that, because of the expansion of scale, congestion diminishes. That impediment, whether or not it can be identified, will earn a negative economic rent which no one will want to collect. Hence the road needs to be subsidized (that is, operated at a loss).

The second parable is an extension of the first. Here it is assumed that there are two roads, either with the same origins and destinations or not. A remarkable fact is that this does not matter. All of the results of the first parable carry over in this case and pertain to each road independently. If the measure, S, as defined before is

now replaced by $S_1$ and $S_2$, each indicating the character of returns to scale on each of the two roads, then road one should be operated at a profit or at a loss depending on whether $S_1$ is positive or negative, and similarly for road two. It should be stressed that this contradicts the common view that one road (or mode) should be taxed to pay for another. Whether one is thinking of roads or alternative modes of transportation, the relationship between the optimal expenditure and the optimal toll for one is independent of the optimal expenditure and toll for the other, except, of course, to the extent that all economic variables are interrelated in that some goods may be substituted in consumption for other goods and factors of production may be put to alternative uses. But there is no more reason to suppose that one mode of transportation should be taxed in order to subsidize another mode than that it should be taxed in order to subsidize the production of bread.

This analysis can also be extended to the case of three or more roads and, because it is unimportant whether they have common origins and destinations or not, the analysis therefore applies to a whole road network.

A third parable introduces a different sort of complication. Suppose that the total amount of productive services available to the economy is not given in advance but itself depends on the amount of travel that takes place. Indeed, it may now be imagined that the trips people wish to make are not pleasure trips desired as such, but are work trips desired because they add to the individual's income. This, it is discovered, makes absolutely no difference in the analysis. Whether the trip is motivated because it is enjoyable or because it leads to increased consumption of something else that is enjoyable is beside the point. The same five conclusions drawn from the first parable are valid in this situation as well.

The fourth parable introduces still a different complication in the original problem. Here it is supposed that the desired intensity of road use differs with two different portions of the day, a peak period and an off-peak period. Traffic intensity, however, is assumed to be sufficiently great so that there is a problem of congestion during both of these sub-periods. This case is very similar to the two-road case because the same route may be regarded as one road during the peak period and as another road during the off-peak period. The major difference is that these two roads are actually the common product of a single expenditure decision, so that the production relations are

$$d_1 = D(\Sigma_i t_1^i, \; E) \tag{3}$$

$$d_2 = D(\Sigma_i t_2^i, \; E) \tag{4}$$

where subscripts 1 and 2 denote roads 1 and 2, respectively. The absence of a subscript on E, indicates that the resources used to produce the first "road" are simultaneously used to produce the second. (This derives from such considerations as the possibility, for example, of heavier policing or of changing lane dividers as between the peak and the off-peak periods.) It is also noted that the function, D, is the same for both periods.

The results for this case are just like those before, except that the optimal road subsidy is more complicated. It may be expressed as

$$E - \tau_1 \sum_i t_1{}^i - \tau_2 \sum_i t_2{}^i = \frac{S^{(1)} \sum_i w^i u^i{}_{d_1} + S^{(2)} \sum_i w^i u^i{}_{d_2}}{D_E{}^{(1)} \sum_i w^i u^i{}_{d_1} + D_E{}^{(2)} \sum_i w^i u^i{}_{d_2}} \tag{5}$$

in which $\tau_1$ and $\tau_2$ are the optimal tolls per trip on each of the two roads, $u_{d_1}$ and $u_{d_2}$ are the decrements (measured as negative) to the satisfaction index of individual, i, of a unit increase in the measure of congestion on roads 1 and 2, respectively, the $w^i$'s are "weights" reflecting the relative importance in the social judgment of the satisfaction levels of the different individuals and reflecting indirectly the decision as to the appropriate distribution of income, and $S^{(1)}$ and $S^{(2)}$ measure the adversity (or, if negative, favorableness) of returns to scale in the road technology on each "road" (i.e., for the same road for each different time of day). This analysis can easily be extended to the case of three or more periods of different traffic flow intensities.

Eq. 5 indicates that if there are adverse returns to scale, the road should be operated at a profit, toll receipts over the entire period exceeding road expenditure; and contrariwise. If there are adverse returns to scale for one sub-period and favorable returns for the other, then whether the road should be operated at a profit or a loss depends on the relative magnitudes of $\Sigma_i w^i u^i_{d_1}$ and $\Sigma_i w^i u^i_{d_2}$. The formulas for the optimal tolls, which are not presented here, are also more complicated than in the earlier parables. Each depends on the way in which the congestion level affects the satisfaction of each individual during both the peak and off-peak periods, and on the weights assigned to measure the relative social importance of satisfaction indexes achieved by different individuals.

The fifth parable is considerably more complicated than those preceeding. It introduces space explicitly in the context of a "classical" city with a "city center" to which people who reside in outlying regions, differentiated as "rings," wish to travel. Individuals' preferences rest on the same things as in the previous parables (the amount of bread consumed, the number of trips made, and the degree of congestion); but, in this parable, they also rest on the amount of square footage available to them for their residences and the distance they live from the city center. The measure of congestion must in this case depend on the residential location of the individual, being greater the farther out he lives. (Congestion is defined here as dimensionally the product of congestion at a point and distance. Thus, although congestion at a point may be less near the outskirts than near the city center, a longer trip from farther out to the center entails greater congestion because congestion in the sense used here is congestion at a point integrated over the distance of the trip.) What is considered is simply a portion of this city, with a fixed population living in a fixed area (though with no outer boundary in the nature of a city limit). All individuals in this area travel to and from the city center using the same arterial route. The individual can use his income to pay tolls, to buy bread, to pay head taxes, and to pay rent for the land that he occupies. One aspect of a pareto optimum now is that people must be allocated residentially to different parts of the city and must occupy parcels of land of different size depending on their preferences, their incomes, and the prices they confront. The individual chooses his bread consumption, the number of trips he makes to the city center, how much land he occupies, and how far out from the city center that land is. Consistent with these free market choices, the same questions are asked as before. What is of special interest to investigate, however, is whether the rent per square foot for land use in a region or ring a given distance from the city center should be the same for all individuals who live there and whether it should be a constant or should instead vary with the size of the lot. In particular, should a surcharge in the form of a land use tax be superimposed upon the land rents generated by a free market in order to raise funds for the payment of the highway? After all, the pattern of congestion will depend on the way in which people sort themselves out over the available space, and it is not evident that each in his private choices will take account of the additional congestion he imposes on others by occupying more space and thus causing his outlying neighbors to travel greater distances under congested conditions.

The result of this analysis is that the very same propositions that emerged from the first parable emerge here as well. Land rents should be those that would be determined by demand and supply in free markets, being so much per square foot regard-

less of quantity and regardless of renter (or owner), depending only on distance from the city center. There should be no surcharge on these land rents in order to raise funds for the cost of the road. The cost of the road, once again, should either exceed, equal, or fall short of the total receipts from optimal tolls depending on whether there are favorable, constant, or adverse returns to scale in the highway technology.

In a final parable, it is demonstrated that if account is taken of the fact that roads themselves use up space that might be devoted to other purposes, all previous results will still stand so long as the rental value of the space used for roads is included in the measured cost of road construction.

For a variety of complications, then, the central result is that (if individuals do not take account of the increased congestion that they themselves experience simply because they make more trips) there does exist a set of optimal tolls and an optimal expenditure on roads. There is, however, no evident way in which these appropriate magnitudes can be found through a market system and they are hard to measure. But the roads need not be exactly self-financing. Depending on whether there are adverse or favorable returns to scale, roads should either more than pay their own way or should be subsidized. And in comparing the case for either the subsidization or taxation of different roads or modes, there is no constraint stating that taxes (or profits) collected from some should be balanced out by the subsidies paid to others.

As an epilogue, a few remarks are in order about where this kind of analysis might lead. All of the parables here reported have dealt with the question of finding a pareto optimum in a situation where there are no practical restrictions on the collection of any scheme of tolls deemed appropriate. As a practical matter, this is, of course, grossly unrealistic. Future research might well be addressed to the problem of what tolls or other levies should be charged and what road expenditures should be if, for example, tolls cannot be varied with time of day as may be required, or cannot be varied with the distance of the trip, or must be the same for different routes, or must in other ways depart from the optimality criteria. These are the so-called problems of the "second best" in welfare economics applied to the matter of urban transportation pricing. They are more difficult problems than those here considered, but extending the present analysis to them might yield more pertinent results.

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