EFFICIENT TOLLS

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July 24, 2001

PROBLEM STATEMENT AND SUMMARY

Urban traffic congestion is widely seen as a "tragedy of the commons", occurring because the use of roads is free, and each individual user may impose an "external cost" of congestion delay on other users, greater than that he himself must pay. “Economically efficient” pricing would add a toll to bring each user's own total marginal, “internal” cost up to that of the marginal congestion his use imposes on all other drivers. For drivers unwilling to pay that toll, i.e. for whom the perceived benefit is not worth the total marginal cost, the trip presumably would not be taken, thereby reducing the volume of low-valued traffic on the road, reducing congestion, and maximizing overall net societal benefits.

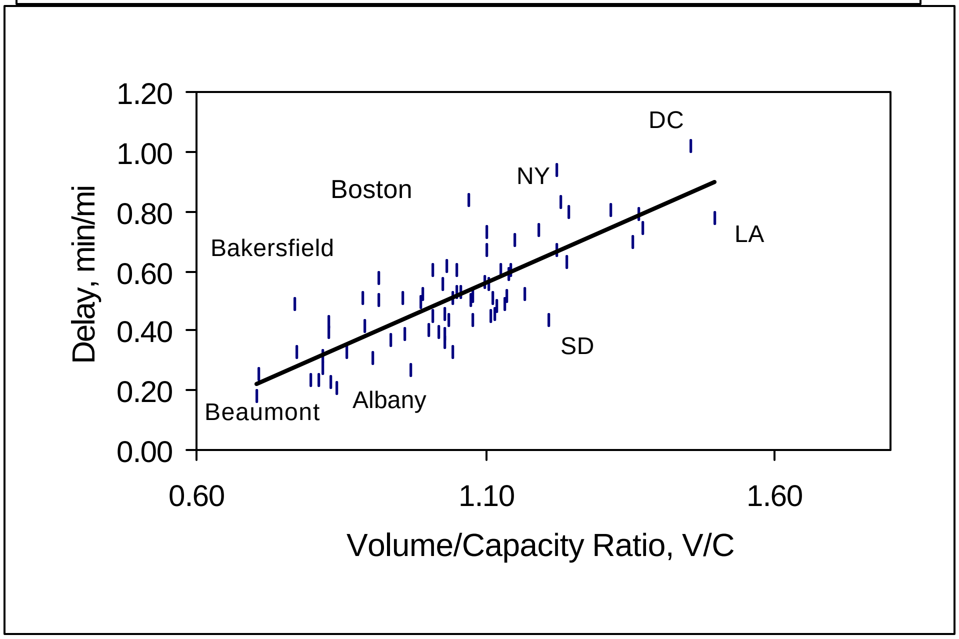
This reasoning, however, rests on the implicit assumption that the marginal external cost of congestion *exceeds* the driver's own marginal internal cost without tolls. Because the marginal driver’s presence impacts an enormous number of other drivers, it may seem obvious that the total marginal cost imposed on others must vastly exceed his own internal cost; however, this is illusory. This paper provides a basis for estimating the marginal internal and external components of travel cost and finds that under common circumstances, on the average, even in highly congested regions like Los Angeles, drivers are already paying an internal cost which under reasonable assumptions may be slightly less or slightly more than the external cost of the total delay (s)he imposes on all others, even *without* tolls, and the economically efficient optimum toll is essentially zero. This raises the interesting issue as to whether such an optimal toll if negative, i.e. a subsidy, is meaningful. It is concluded that in principal, under these circumstances, total net societal welfare would indeed be maximized by paying each driver, out of general funds, an inverse toll (subsidy) equal in magnitude to the excess of his marginal cost over the his imposed external marginal cost. This would, of course, run into serious problems of equity. It appears to be an anomalous result of the fact that “economic efficiency ” is indifferent to equity of distribution of benefits, suggesting the irrelevance of the principle in the real world of traffic management.

BASIS

Due to inevitable equilibrium diversions of traffic in place and time, the external or imposed delay impact of a marginal increment of travel is felt over a wide range of time and place. To evaluate the total impact, we need an approximation of the total regional congestive delay, veh-hr/day or equivalent, over all place and time-of-day as a function of total travel, V, veh-mile/day.

Just such a relationship can be derived from TTI congestion data [1], which show a reasonably strong linear relationship between all-day, all-place, total regional congestive delay, minutes/mile, and the Regional Volume/ Capacity ratio as shown in Figure 1:

Figure 1. Regional Congestion Delay



Each dot here represents one of 70 major US cities. The horizontal axis is the ratio of regional transportation volume, V to regional Capacity, C, both expressed as vehicle-miles per day. The vertical axis is the regional average travel-time delay, minutes per mile.

The data and derivation are discussed in detail in Figure 5 and accompanying discussion in a companion paper [2].

The straight-line regression fit shown can be expressed as an equation:

$$D(V) = (0.86\,(V/C) - 0.38) \quad \text{veh-min/veh-mile} \qquad 1)$$

valid in the range $0.6 < (V/C) < 1.6$ with $r^2 = 0.64$

where

V = total regional travel volume, veh-mi/day, sometimes called DVMT

C = total regional capacity, veh-mi/day, defined as (13,000 x regional fwy lane-miles + 5000 x regional arterial lane-miles)

D = Regional average all-day delay relative to free flow, minutes per mile,

Note that "regional volume" and "regional capacity" as defied here are not the same as "capacity" of a roadway, as defined by TRB and ITE.

This is an imperfect empirical relationship. It fits the underlying data with an r^2 of 0.64, which is to say marginally useful though subject to possibly significant prediction error.

Further, the underlying data (TTI) is subject to the criticism that it is not a direct measure of delay but inferred from the regional total of segment-by-segment delay estimates based on segment V/C ratios and known speed-flow relationships for uniform roadway segments. Nevertheless, while open to improvement (which is understood to be ongoing), that data appears to provide not just the best, but possibly only formally correct, available data basis for evaluating the marginal internal and external delay costs of travel, including global effects due to traffic diversions in time and place. Both Volume, Capacity, and Average Delay here pertain to all-day, regional totals, not just peak-hour.

From 1), total regional congestion delay, *TD(V)* is derived by multiplying delay per vehicle by the regional travel volume, V, veh-mile/day,

$$TD(V) = (0.86\frac{V^2}{C} - 0.38V) \quad \text{veh-min/day} \qquad 2)$$

Then the marginal total delay, MTD, per marginal increment of Regional Volume is the derivative:

$$\begin{aligned} MTD &= \frac{dTD(V)}{dV} \\ &= \left[2 \times 0.86\frac{V}{C} - 0.38\right] \quad \text{veh-min/veh-mi} \end{aligned} \qquad 3)$$

This is the marginal *total* delay (aggregate) suffered by *all* regional travelers (including the marginal user) per unit incremental volume added, dV, veh-mi/day, summed over the entire day, not just peak hour and over an entire region.

Some of this marginal delay is the average Marginal *Internal* Delay, MID, that is, incumbent on the marginal user himself. This is just,

$$\begin{aligned} MID &= D(V) \\ &= \left[0.86\frac{V}{C} - 0.38\right] \quad \text{veh-min/veh-mi} \end{aligned} \qquad 4)$$

At the same time, because of that veh-mi increment of travel, all other travelers will have to "pay" an additional delay, the Marginal External Delay, MED, (veh-min/veh-mi) given by

$$\begin{aligned} MED &= V \times \left[\frac{dD}{dV}\right] \\ &= \left[0.86\frac{V}{C}\right] \quad \text{veh-min/veh-mi} \end{aligned} \qquad 5)$$

It may be confirmed from the above that the marginal internal plus marginal external delay comprise the marginal total delay:

$$MID + MED = MTD \qquad 6)$$

Example

As an example, consider Los Angeles, having the worst regional V/C ratio in the nation, at 1.47. For Los Angeles:

MID = 0.88 veh-min/veh-mile

MED = 1.26 veh-min/veh-mile

MTD = 2.14 veh-min/veh-mile

We see that the external delay exceeds the internal delay by just 0.38 min/mi and that contrary to common intuition, when the external impacts are measured on a regional, all-day round basis, this excess external cost is independent of V/C, that is, the regional congestion level.

It should be pointed out that this implicitly supposes the additional marginal imposed veh-mile of traffic volume to be distributed in time like that of total traffic. This means that actual travel in the peak hours would actually have a somewhat higher impact and travel in off-peak somewhat lower impact than calculated here. Unfortunately, data do not appear to be available to support, as one might wish, the external cost of delay measured, on a regional, all-day basis, (as it must be) due to marginal travel at a particular time of day.

OTHER INTERNAL COSTS

The total marginal internal *cost* of driving, MIC, includes not only delay but two other potentially significant terms, operating costs and tolls:

MIC = AVO * MID/60 *VOT + OC + TOLL , $/veh-mi 7)

where,

VOT = Value of a person-hour of time, $/person-hour

AVO = Average Vehicle Occupancy, persons/veh

OC = Operating Cost, $/veh-mi

TOLL = Toll, $/veh-mi

The marginal *external* cost is similarly,

MEC = AVO * MED/60* VOT $/veh-mi 8)

The theoretical "economically efficient" optimum toll, $TOLL_{opt}$, would be such as to bring the marginal internal cost up to that of the marginal external cost or,

MIC = MEC 9)

In principle, this condition would assure that no one, acting in his own self-interest, would choose to take the trip unless the net value to him was equal to or greater than the total delay cost imposed on everyone else. The net social benefit would thereby be maximized.

Solving for the optimal toll, $TOLL_{opt}$, then,

$$AVO * (0.86\ V/C - 0.38)/60 * VOT + OC + TOLL_{opt} = AVO * (0.86\ V/C)/60 * VOT$$

or

$$TOLL_{opt} = 0.38/60\ AVO\ VOT - OC \qquad 10)$$

DISPOSITION OF TOLLS

The derivation to this point assumed no social benefit from the toll revenues. If we were to assume that a fraction, f, of toll revenues were returned as a social benefit, the Marginal external cost would be reduced by an amount f x Toll so the optimal toll would be further reduced by the fraction 1/(1+f), so equation 10 becomes:

$$\begin{aligned} TOLL_{opt} &= 0.38/60 \times AVO \times VOT - OC - f \times Toll \\ &= (0.38/60 \times AVO \times VOT - OC)/(1+f) \end{aligned} \qquad 11)$$

EXAMPLE

Assumed parameter values:

VOT = $11.99/hr. Based on 80% of regional average wage (FTA Section 5309 New Starts Criteria, Federal Register, November 12, 1997, (http://www.epa.gov/fedrgstr/EPA-AIR/1997/November/Day-12/a29718.htm) and US Average Wage, extrapolated to 2002, $31,177 /yr (http://www.in.gov/doc/compare/income.html) gives $11.99/ hour

AVO = 1.59. National Personal Transportation Survey, 1995, US Average, all purposes, all times of day. http://www-cta.ornl.gov/npts/1995/doc/

OC = $0.118/mi US Average 2002 automobile operating cost estimate by AAA. http://www.ouraaa.com/news/library/drivingcost/driving.html

f = 0 Ignoring the possibility of socially beneficial disposition of the tolls. Some would argue this is a reasonable assumption.

The economic efficiency optimal toll then becomes

$TOLL_{opt}$ = $0.121 – $0.118

= $0.003/mile (less than 1 cent/mile)

WHAT DOES THIS MEAN?

Accounting for the external cost of travel delay imposed over an entire region and all-day, and assuming a uniform value of time, and for marginal travel distributed in time similarly to the ambient traffic volume:

1. Within the range of significance of the assumed parameters, the "economically efficient", optimal toll, here +$0.003/mile, is not significantly different from zero.

2. . Taking into account only the external cost of travel time, the economically efficient or Pareto optimal toll, is far less than has commonly been assumed.

3. The fact that the economic efficiency optimal toll example is slightly greater than zero may be regarded as purely accidental. It could just as well have been negative, raising the interesting issue of what if any is the significance of a negative economically efficient toll (i.e., a trip subsidy). My somewhat uncertain thought on this is that such a negative "optimal" toll, while patently unacceptable from the point of view of equity of *distribution* of such benefits, would indeed maximize social benefits, satisfying the definition of optimal economic efficiency.

4. Congestion management tolls are generally seen in the range of 20¢/mi to $2/mi This being the case it appears likely that there is no overlap between the two objectives, that is a given toll may be designed to meet economic efficiency or congestion control objectives, never both.

5. I conclude that in the context of congestion management pricing, economic efficiency is irrelevant.

REFERENCES

1. Shrank, David, and Lomax, Tim, "The 2001 Urban Mobility Report", The Texas Transportation Institute, Texas A&M University, http://mobility.tamu.edu

2. Mallinckrodt, Jack, "A Multi-Modal Regional Congestion Index", www.urbantransport.org/index1.pdf

3. AAA "Your Driving Costs" http://www.ouraaa.com/news/library/drivingcost/driving.html