TRAFFIC CONGESTION AND WHAT TO DO ABOUT IT

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Traffic congestion on road networks is a fact of life in the modern world: Time is wasted daily on a colossal scale. Things will probably get worse before getting better. What can we do, what should we do about it? Individual efforts seem hopeless; collective action is called for. We approach this as an economic problem from both the supply side and the demand side.

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1. Introduction

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Individual efforts seem hopeless; collective action is called for. We approach this as an economic problem from both the supply side and the demand side.

2. Supply

An obvious possibility is to increase road capacities. The real question then is by how much, to what levels, which is to be discussed below.

In choosing among more roads and alternative uses of land, it is not enough to evaluate these uses by the market value of land alone. Environmental degradation and interference with urban structure and amenities constitute additional 'social' costs. The evaluation of these is a topic in itself, not to be pursued here.

One objection raised against providing road capacities that remain unused or underutilised during off hours can be answered thus: this is a familiar issue in all economic facilities for which demand varies periodically during times of day or over longer intervals, such as electricity generators or sports arenas.

Businessmen on boards of trustees have argued against long college vacations on similar grounds: that the expensive buildings and grounds should not be allowed to stand idle – a gross misunderstanding of the need for pauses in processes of education.

Existing capacities may be augmented by banning parking or even stopping on certain road segments at times of high traffic demands.

An important option is to increase the supply of alternative modes of transportation, even some operating on the existing road networks such as buses, street cars and collective taxis, or through rewarding the transportation of more riders per automobile. Expanding bus supply can take the form of greater frequency or more comfort and convenience. The importance of the latter two factors was discovered in testing modal split models as being relevant to riders' decisions in modal choice.

Other modes running on their own networks can help on a larger scale. These include rapid rail and subways and sometimes ferries. Cost–benefit analysis must compare time and money costs as well as the discomfort of waiting, particularly in inclement weather.

Supply of road capacity to persons travelling can also be increased by excluding freight traffic on certain roads and/or at certain times. Thus, heavy long-distance trucks are prohibited on European roads from Saturday noon to midnight Monday. The Alpine mountain passes in Austria and Switzerland have also been closed to trucks which must now use freeways through tunnels.

Quite generally, travellers from certain origins to certain destinations might be denied travel on a given network. Such discrimination, particularly against foreign travels is contrary to law and international conventions at the present. A milder form of this is to allow access to certain neighbourhood roads to residents only.

Technical progress is not promising to aid the supply side but may offer some help to demand. New breakthroughs are not expected in road design to handle traffic volumes more efficiently or in vehicle design to make driving better under congestion. Improvements in energy use may upgrade air pollution but does not speed travel time under congestion. However, computer aided traffic signal setting at intersections, a technology already available, can speed up traffic flow. Regarding demand: traffic forecasting in real time, while not enforcing a better utilisation of capacities, can yield better decisions in the timing of departures and thus contribute to a smoothing of travel demand whose peaks produce the worst congestion.

3. Demand

There are people (some extremists of the Green party) who would like to do away with automobile travel all together and in some isolated areas – spas and some islands – they have succeeded. Here we restrict ourselves to efforts that can be listed towards discouraging road use, both by carriers and individual travellers.

Automobile ownership is a target from two sides. The industries producing automobiles and the infrastructure that promotes their use are important employers and major sources of tax revenue. On the other side is the concern of an educated public over the growing use of, and reliance on, automobile transportation, among whom environmentalists and urbanists are prominent.

In one of his science fiction novels, H.G. Wells envisions a future human race of diminished body size, the result of nobody's walking anymore. He might be off a little there, but in fact walking is in and fast food is out, in theory at least.

Car ownership and car purchasing is discouraged in fact by special taxes by governments in excess of general sales and property taxes. Such punitive taxes are leftovers from a time when automobiles were seen as a play thing of the rich. There is no sound economic reason for punishing individual auto ownership now and the mobility they provide. Next, the use of a car is discouraged through taxes on car fuel. These are normally defended as payments for the use of roads and charges for their maintenance (on road financing, see below). Generally speaking, the use of particular roads or parts of the road network may be controlled by direct legal prohibitions or more in accordance to the economic freedom we enjoy in a market economy, through charges on road use, that is, tolls.

4. Tolls

We come next to the manipulation of demand at particular times and places. It may be done by direct, legal, prohibition or more in accord with markets through charges for road use, that is, tolls. These may be set at different levels for different times. More effective still is to make tolls a function of the actual traffic conditions, that is, of traffic volume. This is my main subject here and I propose to study it in a simple scenario, as follows.

One Origin O, one Destination D, two roads: one short and congested, one longer and of sufficient capacity to remain uncongested even if all traffic from O to D were routed to it. This example was actually used by the noted economist Frank Knight in a famous debate on policies concerning industries with increasing returns to scale, with the equally known economist Jacob Viner in the thirties.

How will traffic flows arrange themselves here? The short route will be used exclusively until congestion raises travel time to that on the longer route and then all additional traffic will use the longer uncongested route. Is this traffic equilibrium optimal? A simple analysis shows that it is not, because of overuse of the short road. Let *q* be the total demand, *x* the flow on the short route, *f (x)* the travel time there and *g* that on the longer route.

For equilibrium flow $f\ (\ddot{x})\ =\ g,$ (1)

For the optimum $\hat{\ddot{x}}$: $\min\ xf\ (x)\ +\ g\ \cdot\ (q - x),$ (2)

Yielding $f\ (\ddot{x})\ +\ \ddot{x} f\ r(\ddot{x})\ =\ g.$ (3)

Since $f\ '(\ddot{x})\ >\ 0$ under congestion, delays increase with flow, we conclude

$\ddot{x}\ < \hat{x}$. (4)

For optimal use, that is, minimal total travel time, travel time and flow should be less on the con- gested road than in the freely chosen equilibrium. Some travellers should, therefore, be persuaded not to use the congested road, although the travel time would be less than on the longer road, even with some congestion. How can we persuade them? Clearly, not by appealing to their public sense, rather by charging them a road toll. And this toll should be

$\hat{x}f'(\hat{x})$. (5)

Here, $f\ '(\hat{x})$ measures the increase in travel time to everybody on the road caused by one additional unit of flow *x*. The total incremental cost to all users (including oneself) is thus Equation (5). Economists call this a social cost as distinct from the private cost f, that is, actually experienced by the traveller on free roads. This then is the case for congestion tolls.

Where is the improvement? To the road user, the (marginal) cost of travel is still *g*. Those $\bar{x}$ who now save time $g\ \ f\ (x)$ must pay for it with a toll (5) but it is better to ration travel on the short road through money charges than through time lost alone as in the case of no toll. At least, the toll revenue can be used for public purposes, in general, or even better for investments in the road network (see below).

Road pricing is sometimes opposed as allegedly placing an unfair burden on the poor. The opposite is true. Since road tolls are to be set at a level that makes the average road user indifferent between toll road and the longer free road, the richer than average will consider the toll a bargain to purchase time, while the poorer than the average will consider the toll worse than the extra time on the free road. It can thus be argued that the rich benefit more because of the option used by them to save time but the poor are made no worse off. But this is not the main point. That point is the reduction and conversion of wasted time into a public revenue and thereby an increase in the general welfare.

In the examples considered here (for clarity and simplicity), the efficiency gain was achieved by shifting the traffic from a crowded central route to a somewhat longer route with excess capacity. Such a route with abundant capacity may not be within easy reach from a densely built- up metropolis such as Hong Kong. Tolls still have a function: reducing traffic on the worst routes, but in the end, the misery may only be spread and equalised. What if all routes are then congested with only minor differences remaining? Is there any hope without constructing more capacities? There is. Under discussion (as mentioned in the *Wall Street Journal* on February 2) are faster lanes for commuters whose time is particularly valuable. For a toll charge equal to the travel time difference between fast and slow lanes multiplied by the money value of a time unit for the marginal fast lane user (or the most reluctant, slow lane customer), everyone has a choice, but it

is realised only by those more productive, earning the higher return per unit of time.

It is straight-forward to show the gain to the economy of saving time for whom it is most valuable as revealed by their marginal productivity. But the efficiency gain comes now at the expensive of equality. The slower lanes are more crowded to make the faster lanes in fact faster. The condition for optimal efficiency can be stated in a neat formula, which alas is not of real practical use: the efficiency loss (value of time lost) from shifting one car from the fast lane to the

slower lane must equal the toll.

5. The travel time flow function

Some explanation may be in order on the relationship between traffic flow and travel time. In traffic engineering, the basic relationship is the average speed as a function of traffic density: vehicles per km. At very low densities (intended speed) is independent of flow, then decreases because higher (average) speed can be maintained only at wider spacing, that is, at lesser densities of vehicles; until speed falls to zero when cars are literally bumper to bumper. For simplicity, let us approximate the speed–density relationship by a straight line (Figure 1).

$$v = a - \delta,$$

where v is the velocity, δ density, a the maximal average desired speed (with units chosen to make the slope equal 1). The interchanging axis shows that speed v is the inverse relationship; density as a function of speed is then also decreasing and in the illustrative simple case linear (Figure 2).

$$\delta = a - v.$$

Consider next traffic flow x, the product of speed and density as a function of speed is:

$$x = v(a - v) = av - v2,$$

The lower branch is transformed into an upper branch and the upper into a lower, but the structure remains (Figure 5). At lowest levels of flow, the desired speed a translates into a minimal travel

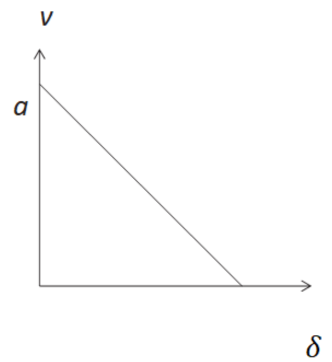


Figure 1. The speed-density relationship of traffic

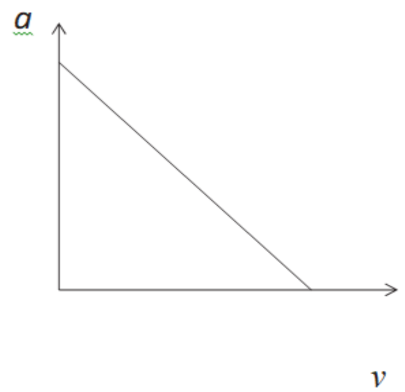
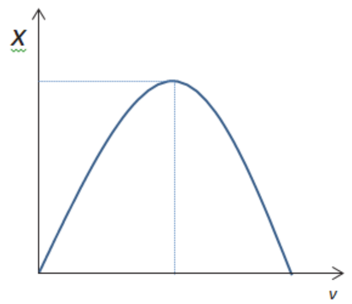


Figure 2. The density-speed relationship of traffic



that densities be kept at levels in the regime of the lower branch, that is, $\delta < a/2$. On the Los Angeles freeways, traffic lights on access ramps, for instance, are meant to serve this function.

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