TRAFFIC STUDIES AND URBAN CONGESTION

By R. J. Smeed

Inaugural Address by the Professor of Traffic Studies at University College London, delivered on 23 October 1967

Like many newly appointed Professors before me, I wondered long what to talk about in my inaugural address. Not only is my chair a new one, but it is in a fairly new field. I should like to show my university colleagues that the study of traffic is intellectually stimulating and that it is possible to organise some aspects of the subject into an interesting and rigorous discipline; I should like to show my more practically minded colleagues and the world at large that we do know something about the subject and that it has something of practical value to offer. I should like to discuss the research now being carried out in this field and the attractions of the subject for students. It is obviously impossible for me to cover all these topics in a talk of limited length, but I propose to do what I can.

I imagine that you hardly require convincing that traffic studies are important. Travel absorbs about 8 per cent of the waking time of those adults who travel on a particular day, and during much of it the traveller is very frustrated. Nearly 20 per cent of the whole national income is spent on transport, and road transport is responsible for about four fifths of that. Road accidents are directly responsible for nearly 2 per cent of all male deaths, including nearly 50 per cent of all male deaths in the 15-19 age group. Not only does traffic have economic and safety effects, but it produces noise, it pollutes the atmosphere and it has adverse effects on the appearance of our towns. But, on the other hand, it gives us extensive opportunities for enriching our lives.

The feeling that something should be done to mitigate the harmful effects of motor vehicles is almost universal, but the opinions on what should be done are wildly conflicting. There are groups in our society who would like to travel everywhere by car, there are other groups who believe that nobody should be allowed to travel by private transport – at any rate in our larger towns – and there are groups with every variety of view in between. There are similar differences of view with regard to the transport of goods. Again, there are groups who put safety above all else and there are others who put ease of travel first. There are groups who want traffic conditions improved, almost regardless of expense, and there are others who believe that almost all other matters should have priority. In addition to the conflicting attitudes between groups of persons, there are internally conflicting views. Many of those people who are most anxious to have new roads built, or other traffic facilities made available, object most strongly when they find that some new traffic facility will involve a new road taking off a piece of their garden, or that it will take more traffic past their house.

One of the tasks of the scientist in the traffic field must be, I think, to produce an
objective and comprehensive account of the factual elements underlying the problems and to see to what extent the underlying aims behind the opinions expressed can be reconciled. If this can be done, there is some possibility of turning the great interest in traffic problems to useful ends.

We study traffic for very practical reasons. We do so in the hope that our studies will lead to effective measures for facilitating traffic flow and for reducing its harmful effects. But my primary object today is not to bring particular measures to your attention. Instead it is rather to consider whether we can obtain an understanding of some of the factors on which the movement of traffic depends and how far such an understanding can throw light on measures for reducing the difficulties which traffic experiences and causes. But, as it is necessary to restrict the field of discussion, I propose to spend nearly all the time I have available in discussing the difficulties which traffic experiences in the central areas of towns during peak travel periods. I must, however, emphasise that even within this restricted field I cannot, in the time available, consider all the aspects. I shall not, for example, discuss at all the effects which traffic has on amenity or on accidents, although both are vital considerations, and I shall not consider many of the economic aspects. In consequence, nothing I say should be interpreted as meaning that I advocate particular measures; I shall merely point out some of the advantages and disadvantages of various measures.

Now I propose to discuss the congestion problems in towns, and these problems arise owing to the large amounts of traffic. It is therefore to be expected that there would be advantages in dealing with the subject quantitatively, and this is what I propose to do.

THE CAPACITY OF A ROAD NETWORK IN A TOWN CENTRE

The Width of Road required for Travel

I start by considering the number of vehicles that an urban road system can accommodate, and I shall consider first the number that can use a single road. A number of investigations have been carried out on this, and some results have emerged. It has also been found that there are fairly definite relationships between the amount of traffic on a road and

(1) the speed of traffic between intersections [1] and

(2) the delay experienced by traffic at intersections [2].

My colleague, Wardrop, has combined these relationships to produce the relationship shown in Figure 1, which applies to roads with the approximate frequencies of intersections and widths found in Central London and many other towns. There are advantages in expressing this relationship in the form of an equation. A suitable one which he devised is

\[
\frac{\text{No. of cars using road per hour}}{\text{Width of road (in feet)}} = 68 - 0.13v^2
\]

where \(v\) is the average speed of traffic in miles per hour.* Some of the vehicles will,

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*In a previous analysis [3] a slightly different formula was used. (Flow per unit width = 58.2 - 0.00524\(v^2\).) The two formulae give very similar results for speeds above 10 miles per hour, but the present one fits the low speed data rather better.
of course, be buses, bicycles, etc. We get over this by regarding a bicycle as the equivalent of one-third of a car, a bus as the equivalent of three cars, and so on. I shall not spend time discussing the full justification for this, but you will see from the graph, which gives the results of measurements of journey speeds by Thomson [4], that the method works to a fair extent.

In order to make a comprehensive yet simple analysis, I propose to use this equation throughout the analysis contained in this paper, although it does not apply exactly to all roads. Its chief defects are that it underestimates speeds slightly on roads with few intersections per mile and that it overestimates speeds to some extent on narrow roads. Sufficient observations are, unfortunately, not available to make it possible to give accurate estimates of the likely error, but this error is certainly no greater than others that I propose to accept. I shall discuss the likely effects of errors in my assumptions later.

The equation suggests that we may regard each car using the road, during a one-hour period, as requiring a width

\[
\frac{1}{68 - 0.13v^2}
\]

feet

in order to travel at a speed of \(v\) miles per hour. A bus would require three times this width.
The Average Length of a Journey during the Peak Travel Period

I have obtained a formula for the width of road required per vehicle and now propose to consider the average distance travelled; I shall confine my discussion to travel in the central areas of towns.

The average distance travelled depends on the type of road network, the distribution of origins and destinations and other factors. But I am now concerned with the capacity of the road network and, therefore, mainly with travel at peak travel periods. At such times, journeys are predominantly between points on the outskirts of the central area of the town and scattered points inside it. For simplicity, I shall refer to the morning peak period, although the results apply equally well to the evening peak. It is therefore convenient to assume initially that origins are equally distributed amongst the points at which the roads leading into the central area meet its boundary, and that destinations are distributed either uniformly along the sides of the roads of the central area or uniformly within the area. Under such conditions, it is possible to calculate the average distance travelled on the roads of any given town centre, assuming that journeys are made by the shortest possible route. With the assistance of a colleague, I have made approximate calculations for a number of idealised and real road systems [3], for example, those shown in Figure 2. In all realistic cases, the average distance was found to lie between $0.70A^4$ and $1.07A^4$, whilst the mean value was found to be $0.87A^4$, where $A$ is the area of the town centre.* It seems likely therefore that, if we assume as a very rough approximation that the average distance travelled is $0.87A^4$, the results will not usually be subject to very large errors.

A Formula for the Numbers of Vehicles that can reach their Destinations per hour in a Town Centre

I showed earlier that, for journeys during a peak travel period of one hour, the average car, or car equivalent, requires a width of road $\frac{1}{68-0.13v^2}$ feet. We now see that the average distance travelled is $0.87A^4$. It follows that, for journeys during a peak travel period of one hour, the average car, or car equivalent, requires an area of carriageway $\frac{0.87A^4}{68-0.13v^2}$ square feet† for its journey in a central business district. If $Q$ vehicles are to travel in the town centre during this period, the area of carriageway required will be $Q$ times this quantity or $\frac{0.87A^4Q}{68-0.13v^2}$ square feet.

*After this paper was written my attention was drawn to some calculations by Thomson [5] on some average distances travelled in a sample of journeys in Central London (as defined in the London Travel Survey [6] area 10.43 square miles). His data, taking means of his results for 1960 and 1967, give external-internal journeys $0.70A^4$, internal journeys $0.87A^4$, through journeys $1.22A^4$ and overall average $0.87A^4$.

†It may be noticed that this expression is not dimensionally correct. The same applies to a number of other expressions and equations in the paper. It is therefore essential that these expressions and equations be used only when expressed in the units specified.
Fig. 2

AVERAGE DISTANCE TRAVELLED ON SOME IMAGINARY AND REAL ROAD NETWORKS

\[ d = 0.80A^{\frac{1}{2}} \]

\[ d = 0.78A^{\frac{1}{2}} \]

\[ d = 0.81A^{\frac{1}{2}} \]

\[ d = 0.83A^{\frac{1}{2}} \]

\[ d = 0.86A^{\frac{1}{2}} \]

\[ d = 0.97A^{\frac{1}{2}} \]

Reading

Cambridge

--- Roads
---- Boundary of network
A Area within boundary
d Average distance travelled
Now, if the fraction of the carriageway area available for traffic movement of the type under consideration is \( f \), and \( f \) is the fraction of the total ground area of the town centre devoted to roads, it follows that the total ground area available for the traffic under consideration is \( JfA \). For the journeys to be made at the speed specified, the area of carriageway required must be equal to the area available.

\[
\text{Hence } \frac{0.87A^1Q}{68-0.13v^2} = JfA.
\]

It follows that

\[
Q = \frac{(68-0.13JfA^1)}{0.87}
\]

\[
= (78-0.155v^2)JfA^1.
\]

I have obtained data for the amounts of traffic entering or leaving the central areas of eight towns during peak travel periods, together with the values of \( v \), \( f \) and \( A \), and from these I have deduced a value of \( J \) for each town centre. The results are shown in Table 1.

**Table 1**

*Estimated values of \( J \),* the proportion of the road system effectively used by traffic entering during the morning peak travel period

<table>
<thead>
<tr>
<th>Town</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maidenhead</td>
<td>0.22</td>
</tr>
<tr>
<td>Bradford</td>
<td>0.23</td>
</tr>
<tr>
<td>Leeds</td>
<td>0.32</td>
</tr>
<tr>
<td>Watford</td>
<td>0.41</td>
</tr>
<tr>
<td>Maidstone</td>
<td>0.42</td>
</tr>
<tr>
<td>London</td>
<td>0.46</td>
</tr>
<tr>
<td>Reading</td>
<td>0.46</td>
</tr>
<tr>
<td>Leicester</td>
<td>0.46</td>
</tr>
</tbody>
</table>

*The values of \( Q, f, A \) and \( v \) from which these results are deduced are given in Appendix 1.*

The table suggests that effectively between 23 per cent and 46 per cent of the road system in our towns is used by traffic entering during the morning peak travel period and, of course, by outbound traffic in the evening. Taking the largest value of \( J \), we get

\[
Q = (36 - 0.069v^2)fA^1
\]

for the maximum numbers of vehicles that can enter a town per hour during the morning peak. Taking the lowest value of \( J \), we get

\[
Q = (18 - 0.0345v^2)fA^1
\]

for this number. The curves corresponding to these equations are shown in Figure 3 (see Appendix 1).

In all the towns for which I have data, the speed of travel during peak periods is between 6 and 14 miles per hour. If the above formulae hold, the numbers of vehicles that could enter an urban road system during the morning peak period or leave during the evening peak would be expected to be between \( 11fA^1 \) and \( 34fA^1 \) car equivalents per hour.

With the help of local highway engineers and others in many parts of the world, I have obtained data on \( f, A \) and \( Q \) for a large number of town centres for travel during peak travel periods. The values of \( Q/fA^1 \) deduced from these data are given in Table 2.
Fig. 3

NUMBERS OF VEHICLES THAT CAN USE A TOWN CENTRE PER HOUR AT VARIOUS SPEEDS

You will see that all the available data give values of $Q/fA^4$ in approximately the expected range found above, i.e. 11 to 34. The above formulae do, therefore, seem to give some idea of the amounts of traffic under peak travel conditions. It can also be easily shown that they give fairly realistic estimates of speed under light traffic conditions, for, by putting $f = O$, we get $v = 23$ miles per hour, a typical average speed in town centres in light traffic. Although the formulae cannot possibly be regarded as satisfactory under all conditions, they clearly give some realistic results over a fairly wide range. I propose to use them in an attempt to throw light on traffic conditions during peak travel periods. For simplicity, I shall use the formula corresponding to the higher value of $J$, but for many purposes the results will apply equally well to both values. I shall use the formula on a number of occasions and, needing a word for it, I shall simply refer to it as the formula.

I must point out that, although the formula will not necessarily always give an accurate estimate of the relationship between the various quantities involved, it does so sufficiently well to enable us to estimate broad relationships. This is all I need in this talk, in which I shall not usually be considering particular towns. You will, however, see that if we took the upper curve of Figure 3 the actual flow for a given speed would be up to 50 per cent less than the predicted value, but there is little


Table 2

Values of $Q/fA$

$Q =$ car equivalents in peak hour in peak directions.  
$A =$ area of a town centre in square feet.  
$f =$ fraction of ground area that is carriageway.

<table>
<thead>
<tr>
<th>Great Britain</th>
<th>Elsewhere</th>
</tr>
</thead>
<tbody>
<tr>
<td>Edinburgh</td>
<td>St. Helier, Jersey, Channel Isles</td>
</tr>
<tr>
<td>Bradford</td>
<td>Salisbury, Rhodesia</td>
</tr>
<tr>
<td>Maidenhead</td>
<td>Leiden, Netherlands</td>
</tr>
<tr>
<td>Darlington</td>
<td>Dublin, Ireland</td>
</tr>
<tr>
<td>Liverpool</td>
<td>Hamburg, Germany</td>
</tr>
<tr>
<td>Hull</td>
<td>Lisbon, Portugal</td>
</tr>
<tr>
<td>Nottingham</td>
<td>Tel-Aviv, Israel</td>
</tr>
<tr>
<td>Leeds</td>
<td>Denver, Colorado, U.S.A.</td>
</tr>
<tr>
<td>Sheffield</td>
<td>Stockholm, Sweden</td>
</tr>
<tr>
<td>Exeter</td>
<td>Goteborg, Sweden</td>
</tr>
<tr>
<td>Cardiff</td>
<td>Madrid, Spain</td>
</tr>
<tr>
<td>Birmingham</td>
<td>Washington, D.C., U.S.A.</td>
</tr>
<tr>
<td>Coventry</td>
<td>The Hague, Holland</td>
</tr>
<tr>
<td>Watford</td>
<td>Copenhagen, Denmark</td>
</tr>
<tr>
<td>Bristol</td>
<td>Los Angeles, California, U.S.A.</td>
</tr>
<tr>
<td>Reading</td>
<td></td>
</tr>
<tr>
<td>Leicester</td>
<td></td>
</tr>
<tr>
<td>Maidstone</td>
<td></td>
</tr>
<tr>
<td>London</td>
<td></td>
</tr>
<tr>
<td>Glasgow</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Possibility of material error in the opposite direction. These degrees of accuracy are sufficient for the purposes of this paper, which discusses the urban problem generally without much reference to particular towns. I should, however, point out that it is inappropriate to use the formula at very low speeds, say, less than 3 miles per hour, since at such speeds the assumptions on which the formula is based are no longer applicable.

We have now obtained a formula for the number of vehicles that can use a town centre per unit time. I propose to use it together with other results to draw conclusions on:

1. the general nature of the congestion problem;
2. some possible changes in vehicles and their use that would help to relieve traffic congestion;
3. some possible changes in roads and in their use.

I shall then attempt to draw some general conclusions.

Effects of the Amount of Traffic on Times of Travel

I shall consider first the effect of the amount of traffic in a town on journey times. The relation can be deduced from the formula and is summarised numerically in Table 3.

40
Table 3
The relation between the amount of traffic and journey time

<table>
<thead>
<tr>
<th>Ratio:</th>
<th>Traffic maximum traffic</th>
<th>Journey time per mile (minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light traffic</td>
<td></td>
<td>2.6</td>
</tr>
<tr>
<td>25%</td>
<td></td>
<td>3.0</td>
</tr>
<tr>
<td>50%</td>
<td></td>
<td>3.7</td>
</tr>
<tr>
<td>75%</td>
<td></td>
<td>5.3</td>
</tr>
<tr>
<td>93%</td>
<td></td>
<td>10.0</td>
</tr>
<tr>
<td>98%</td>
<td></td>
<td>18.5</td>
</tr>
</tbody>
</table>

The table shows that when traffic is extremely light the average time taken to travel one mile in a town centre is about 2.6 minutes. Under these conditions, a considerable amount of extra traffic has a comparatively small effect on journey time. For example, 25 per cent of the maximum possible traffic results in journey times only 12 per cent higher. Even when the traffic is 50 per cent of its maximum, the journey time per mile is only about 40 per cent greater than the journey time under light traffic conditions. However, when traffic is near its maximum, a small increase in the amount of traffic has a large effect on journey time. Thus, when the amount of traffic is 75 per cent of its maximum, an additional 18 per cent nearly doubles the journey time, making it nearly four times as much as under light traffic conditions. When traffic is 98 per cent of its possible value, the average journey time per mile is 7 times as much as under light traffic conditions, and traffic is nearly at a standstill.

This raises the question: why has not traffic in our cities been brought to a standstill already? We have had serious congestion in almost all the major cities of the world for many years. Yet the number of licensed motor vehicles has continued to increase without the traffic coming to a stop, except on rare occasions. The reason is clear. It is hardly to be expected that people would come to the outskirts of a city, stay there for some hours and then go home again, on a large number of occasions. It is much more likely that they would change their home or workplace, travel by train instead of car or bus, or stay at home. Thus the amount of traffic adjusts itself to a barely tolerable speed. It is worth while considering the mechanism of this adjustment.

The Variability of Journey Speeds from Day to Day

When deducing a relation between the speed of traffic and its amount, I referred to the average speed. I will now consider the variability of speeds from day to day. Measurements of speeds on the same roads, at the same time of day, have been made in several towns on a series of days. The observations show that the journey speeds are not constant, and some aspects of the variability are shown in Table 4.

When the average speed is 20 miles per hour, one journey in 20 will take 33 per cent longer than the average. When the average speed is 10 miles per hour, one journey in 20 will take 70 per cent longer than average. When the average speed is 5 miles per hour, one journey in 20 will take 230 per cent more than the average [7]. Thus, the lower the average speed the greater the variability of journey times. Now, long journey times such as the 40 minutes for a one-mile journey shown in Table 4
are, to many people, quite intolerable even though they only occur occasionally; and these people give up making the type of journey concerned. The result of all the choices that people make is that traffic adjusts itself to the available capacity and that there is an oscillation about an equilibrium speed which, for Central London as a whole, averages about 9 miles per hour during the peak hour and about 11 miles per hour during normal working hours. Similar results, and sometimes even lower speeds, are obtained for other towns. One might perhaps expect even lower speeds in smaller town centres, where distances are shorter.

**Time Losses due to Congestion**

We have discussed the speed of traffic in towns and concluded that traffic adjusts itself to a barely tolerable level. I now propose to consider the time losses involved in travelling at these speeds. The time loss on a road can be defined as the difference between the actual time taken by vehicles travelling on the road and the time that they would take under light traffic conditions. It is then found that the lower the traffic speed the higher the increase in time loss due to a given increment in traffic. The effect of increases in traffic on the time loss can be calculated from the formula, and some results are shown in Table 5 (see Appendix 2).

**Table 5**

<table>
<thead>
<tr>
<th>Average speed (miles per hour)</th>
<th>Percentage increase in time loss</th>
<th>Percentage increase in traffic</th>
</tr>
</thead>
<tbody>
<tr>
<td>23</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>15</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>10</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>5</td>
<td>14</td>
<td>14</td>
</tr>
</tbody>
</table>

Thus when the prevailing speed is 15 miles per hour a one per cent increase in traffic will result in a 3 per cent increase in the time lost by congestion. When the prevailing speed is 5 miles per hour a one per cent increase in traffic will result in a 14 per cent increase in time loss.

The effects of additional traffic can be put in another way. This is done in Table 6, which refers to the time loss imposed on other vehicles by a single extra car inserted into a traffic stream (see Appendix 3).
### Table 6

*Time losses imposed on other vehicles by the addition of one vehicle to a traffic stream*

<table>
<thead>
<tr>
<th>Speed of traffic (miles per hour)</th>
<th>Ratio: Time losses imposed on other vehicles</th>
<th>Time taken for journey</th>
</tr>
</thead>
<tbody>
<tr>
<td>23</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>0.15</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>2.0</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>10.0</td>
<td></td>
</tr>
</tbody>
</table>

Under light traffic conditions, one extra vehicle imposes little time loss on other vehicles; but as traffic increases and the speed of traffic falls in consequence, the time loss imposed by each extra vehicle increases. When the average speed of traffic is 13 miles per hour, an extra car or car equivalent in a traffic stream imposes time losses on other vehicles equal in total to the time taken for its own journey. At 10 miles per hour the time losses imposed on other vehicles total twice its own journey time, and at 5 miles per hour the time losses imposed total 10 times its own journey time. A single car or light vehicle making a journey of one mile on a road on which the speed of traffic is 5 miles per hour will typically impose time losses on other vehicles totalling about two vehicle-hours or, perhaps, 4 person-hours. (The average occupancy of all vehicles, including buses and commercial vehicles, is about two for London during peak travel periods).

#### The Proportion of Carriageway occupied by Vehicles

We have discussed the limits – under existing conditions – to the numbers of vehicles that can travel in a town centre per unit time, and the sort of speeds and time losses that occur when the numbers are near this limit. There is, however, no obvious fundamental reason why the position should not be improved. When travelling by air over a congested urban area one may be surprised by the apparent emptiness of the roads (see, for example, Plate 1). The formula makes it possible to calculate the number of vehicles or, more exactly, car equivalents that can travel to a town centre in the morning peak, or from it in the evening peak. Multiplying this number by the average plan area of a car, about 70 square feet, we get an approximation to the proportion of carriageway occupied at any moment, assuming that the area occupied by a vehicle is approximately proportional to its car equivalent (see Appendix 4). This gives a lower limit to the percentage of carriageway covered, because it neglects traffic travelling in the opposite direction to the major movement. An upper limit clearly can be obtained by doubling the figures. The results, together with figures for the effective area “occupied” by each car equivalent, *i.e.* the ratio of the total area of carriageway to the number of car equivalents present, are given in Table 7.

Thus, even when the average speed of traffic is as low as 5 miles per hour, only between 8 and 16 per cent of carriageway is covered by vehicles at any moment, and the area of carriageway per car equivalent present is between 450 and 900 square feet. When the average speed is 15 miles per hour, the proportion of ground covered falls to 1¼ to 3 per cent and the area of carriageway per car equivalent present is
Plate I
Traffic in Kingston, London, Thursday, 30 May 1963, 3.15 p.m.

Table 7
Fraction of carriageway occupied by vehicles

<table>
<thead>
<tr>
<th>Speed (miles per hour)</th>
<th>Percentage of carriageway occupied</th>
<th>Effective area of carriageway per car equivalent present (square feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>4—1</td>
<td>7,250—14,500</td>
</tr>
<tr>
<td>15</td>
<td>3—3</td>
<td>2,250—4,500</td>
</tr>
<tr>
<td>10</td>
<td>3—7</td>
<td>1,050—2,100</td>
</tr>
<tr>
<td>5</td>
<td>8—16</td>
<td>450—900</td>
</tr>
</tbody>
</table>
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2,250 to 4,500 square feet. Investigations might well make possible a much greater use of the carriageway space available, and it is conceivable that, given appropriate changes in vehicles and roads, the number of vehicles that could use an urban road system could be several times the existing number.

I have now considered some general aspects of traffic in town centres. With these in mind, I propose to consider what can be done to relieve the congested conditions that occur. To do this, we can alter the vehicle and/or the way it is used, or we can alter the road system and/or the way it is used. I will consider these in turn, and will start by considering the numbers of persons that can enter a town centre by car and bus.

THE POSSIBILITY OF TRAVELLING TO WORK BY ROAD

Specifically, I propose to use the formula to consider the possibilities of commuters travelling to work by road in town centres of various sizes. But use of the formula requires a knowledge of the values of various quantities, and I must therefore discuss these first.

The Area of the Town Centre

Some information on the area of ground per workplace in various town centres is given in Table 8.

Table 8

<table>
<thead>
<tr>
<th>Area of ground per workplace</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Town</strong></td>
</tr>
<tr>
<td><em>Central London Boroughs</em></td>
</tr>
<tr>
<td>City</td>
</tr>
<tr>
<td>Holborn</td>
</tr>
<tr>
<td>Westminster</td>
</tr>
<tr>
<td>Marylebone</td>
</tr>
<tr>
<td>Total Central London</td>
</tr>
<tr>
<td>†Birmingham</td>
</tr>
<tr>
<td>†Glasgow</td>
</tr>
<tr>
<td>†Manchester</td>
</tr>
<tr>
<td>†Bristol</td>
</tr>
<tr>
<td>†Leicester</td>
</tr>
<tr>
<td>†Nottingham</td>
</tr>
<tr>
<td>†Coventry</td>
</tr>
<tr>
<td>†Exeter</td>
</tr>
<tr>
<td>§Minneapolis, U.S.A.</td>
</tr>
<tr>
<td>§Tucson, U.S.A.</td>
</tr>
<tr>
<td>§Chattanooga, U.S.A.</td>
</tr>
<tr>
<td>†Madrid, Spain</td>
</tr>
<tr>
<td>†Lyon, France</td>
</tr>
<tr>
<td>†Copenhagen, Denmark</td>
</tr>
<tr>
<td>†The Hague, Netherlands</td>
</tr>
</tbody>
</table>

*Calculated from data given in Statistical Appendix to County of London Development Plan.
†Data obtained from authorities concerned.
†Inner area 140, outer area 480.
In 85 per cent of the cases for which information is available the area per workplace is between half and double the figure for Central London. I shall assume initially the figure for Central London and then consider the effect of other densities.

The Proportion of the Town Centre used for Carriageway

Appendix 1 shows that the fraction of the ground in the town centre used for carriageway varies between 10 and 21 per cent in a number of British cities, and that higher proportions occur in some United States towns. I shall assume initially a fraction 14 per cent, the figure for Central London.

Vehicle Occupancy

During peak travel periods, car occupancy has been found to average about 1.45 in London and in other towns in this country and abroad. Observations made in London in 1965 [8] showed an average bus occupancy of 42.5 across the boundary of the central area in the peak direction during the peak hour. This figure will be assumed initially. It is reported by London Transport (personal communication) that the figure fell by 15 per cent between 1960 and 1966. It might, therefore, be lower in future.

Commercial Traffic

When using the formula to evaluate the numbers of passenger vehicles that can use the road system during a given period, it is necessary to make some assumption as to the numbers of non-passenger-carrying vehicles in use at the time. Some data on the composition of traffic entering and leaving the central areas of six towns during peak travel periods were collected by the Road Research Laboratory in 1964 and kindly made available. Calculations from the data show that the percentages of commercial traffic – measured in car equivalents – were 26 for Watford, 28 for Leeds, 31 for Cardiff, 33 for Bishops Stortford and 37 for Maidenhead. A corresponding investigation for London gives a figure of 28 per cent. I assume a proportion of 30 per cent in all towns.

Buses

The formula we obtained for car use cannot be applied directly to buses because the cars of car commuters stop at their destinations, while buses travel right across the town, and also because buses travel by less direct routes than cars. Because of this, the average length of a bus journey in the town centre is effectively about 60 per cent longer than that of a car (see Appendix 5).

Duration of Peak Travel Period

The numbers of commuters that can enter or leave a town is, of course, proportional to the duration of the peak travel period. Experience has shown that this is rarely more than about two hours, and I shall assume this value.

Speed of Traffic

The speed of traffic in many town centres is between 6 and 12 miles per hour, or less during peak traffic periods. I shall assume a speed of 9 miles per hour in order to obtain a practical capacity of a road network. This corresponds to about 85 per
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cent of the ultimate capacity of the road network. Any different assumptions in the speed range 6-12 miles per hour would make little difference to the results of the calculation.

Making these assumptions we get the results in Table 9 (see Appendix 5).

**Table 9**

**Percentage of commuters that can travel to their destinations**

**by car or bus during peak travel periods**

*Assumptions:*

Area of town centre (square feet) = 333 \times \text{number of commuters}.

14 per cent of ground in town centre used as carriageway.

30 per cent of carriageway absorbed by commercial vehicles.

1.45 persons per car, 42.5 passengers per bus.

Duration of peak travel period = 2 hours.

\[ Q = (36-0.0696^2)fa^4. \]

<table>
<thead>
<tr>
<th>Number of commuters (thousands)</th>
<th>Percentage of commuters that can travel by car</th>
<th>Percentage of commuters that can travel by bus</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>285</td>
<td>1,800</td>
</tr>
<tr>
<td>10</td>
<td>155</td>
<td>970</td>
</tr>
<tr>
<td>30</td>
<td>90</td>
<td>560</td>
</tr>
<tr>
<td>100</td>
<td>49</td>
<td>310</td>
</tr>
<tr>
<td>300</td>
<td>28</td>
<td>180</td>
</tr>
<tr>
<td>1,000</td>
<td>16</td>
<td>97</td>
</tr>
<tr>
<td>3,000</td>
<td>9</td>
<td>56</td>
</tr>
</tbody>
</table>

In the table, a percentage of more than 100 means that there is more than enough road space for vehicles to travel at 9 miles per hour. In this case the duration of the peak travel period would – in practice – be shorter than 2 hours, or the travelling speed higher than 9 miles per hour, or both. For different values of the various quantities involved, the numbers of commuters that can reach their destination by car or bus can be calculated from the table, using the fact that the numbers are proportional to the fraction of the central area used for roads, to the vehicle occupancy, to the duration of the peak travel period, to the square root of the area of town centre per workplace, and to the difference between unity and the fraction of commercial to total traffic, measured in car equivalents. The table shows that – on the assumptions made – 6.2 times as many commuters can travel into a town centre by bus as by car. But all the commuters in a town centre of up to 24,000 workplaces could travel by car, whilst all the commuters in a town centre of up to 935,000 could travel by bus. It would not be possible for all the commuters in London, which has about 1,300,000 commuters, to travel by bus, unless commercial vehicles were excluded or the peak period lengthened.

The maximum area of a town centre, assumed to be proportional to the number of workplaces, to which all commuters could travel by car or bus is proportional to the square of the vehicle occupancy and to the square of the fraction of town centre used for roads. It is also proportional to the area of town centre per workplace and

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to the square of the difference between unity and the fraction of commercial to total traffic. Thus, the town centre with 24,000 car commuters obtained above could take 54,000 if the fraction of the town centre devoted to roads were 0.21 instead of 0.14. The figure would be 96,000 if the average car occupancy could be raised to three, the fraction of ground area used for roads still being 0.14. If, in addition, 21 per cent of the ground area were used for roads, it would be 216,000. If also all commercial traffic were excluded during peak travel periods, all commuters could travel by car in a town centre with over half a million commuters.

The Time taken for Travel by Car and Bus

I have discussed the possibilities of travel by car and bus. The time taken for the journey is, however, also relevant. Except for the times spent parking and unparking cars, waiting for buses and walking, journey times can be calculated from the formula, provided appropriate additional assumptions are made to account for the different travel times by bus and car. Calculations are given in Appendix 7 and the results are given in Figures 4 and 5. Figure 4, which gives the times spent by bus and car

![Diagram of time for journeys within town centres](image-url)
Fig. 5

AVERAGE TIME FOR JOURNEYS WITHIN TOWN CENTRES (EXCLUDING WALKING AND WAITING TIMES)

Average time (minutes)

333 sq.ft. per workplace
1.45 persons per car
42.5 persons per bus

300,000 commuters
100,000 commuters
30,000 commuters
10,000 commuters
3,000 commuters

Percentage of commuters travelling by car

 travellers separately, shows that – as is to be expected – the journey time of each of these classes of travellers increases as the proportion of car travellers increases. The rate of increase of journey time with the proportion of people travelling by car is small for small towns, but increases markedly with the size of town centre. It is worth noticing that, for towns of any size, the vertical distance between the curves is more or less constant, so that the difference between the travel times of bus and car travellers is more or less independent of the proportion of car commuters.

Although times spent in their vehicles by car and bus travellers rise as the proportion of car travellers increases, it does not follow that a net advantage would be gained by reducing the number of car travellers to zero. Figure 5 gives the average time of travel for all proportions of car users and shows that, in some circumstances, the average time of travel falls as the proportion of car commuters rises. This is because the increase in journey times of those bus travellers who continue to travel by bus is more than counterbalanced by the reduction in journey times of those travellers who change from bus to car. The graph shows that – on the basis of the
assumptions made – the greater the proportion of cars, the less the average time of vehicular travel for a town centre of 10,000 commuters, which might well be a town of say 100,000 population. Even for a town centre with 30,000 commuters the average time taken, when 80 per cent travel by car, is not materially greater than if they all travelled by bus. In these circumstances, preventing the use of cars would not reduce the total time spent travelling. This conclusion is, in fact, appreciably stronger than is indicated by the diagram, since the diagram omits walking and waiting times, which are much longer than vehicle journey times. For really large towns, however, there could be – on the assumptions made – a real gain in average journey time by a reduction in the proportion of cars.

This conclusion naturally suggests that consideration be given to London. In doing this, however, we should not regard the average area of town centre per commuter as the actual value of 333 square feet, since only 29 per cent [8] of the commuters travel by road. The city centre should more appropriately be regarded as having an area per workplace of 1,150 square feet, and a total number of 370,000 road commuters [8]. The results of the consequent calculations are given in Figure 6. This shows that, compared with the time taken if everybody travelled by bus, the average time of travel is not much altered if up to 20 per cent travel by car, but is about 80 per cent larger if 40 per cent travel by car. If, with 40 per cent travelling by car, car occupancy could be raised to 2.9, double the existing figure, the average time of vehicular travel would be only 5 per cent greater than if everybody travelled by bus. At present 38 per cent travel by car, 7 per cent by motorcycle and pedal cycle, and 54 per cent by bus.

A satisfactory assessment of the net changes in time loss would, however, require some assessment of the time spent parking and unparking vehicles, walking between car parks and destinations, and waiting for buses.

Sufficient data are, unfortunately, not available, but we need not give up entirely, because we can obtain the conditions under which there will be a net decrease in travel time if car commuters change to travel by bus. If we denote by $t_p$ the average time of vehicular travel when a fraction $p$ of commuters travel by car, and by $t_b$ the average time of vehicular travel when they all travel by bus, the gain in vehicular journey time if everybody travels by bus is $(t_p - t_b)$ multiplied by the total number of commuters. This must be compared with the excess time spent by former car commuters in walking and waiting for a bus over the times they would have spent in parking and unparking. The extra walking and waiting times that would outweigh the loss of time to bus commuters can therefore be calculated, and are given in Figure 7. This extra time is 8 minutes if 10 per cent of road commuters are travelling by car, but 32 minutes when 40 per cent are travelling by car. Despite the absence of detailed information on the extra time taken by car commuters as a result of being forced to travel by bus, we can draw some conclusions, since it is certain that many car commuters would take more than 8 minutes extra in walking and waiting and that many would not spend 32 minutes extra. If all cars were banned in Central London, and if the present car commuters switched to travelling by bus, there would be a reduction in the average time of travel; but, to obtain the maximum reduction in time of travel, some car commuting should be permitted, even at peak travelling hours. This calculation assumes, of course, that the increased speeds would not result in more travel into the town centres.
Fig. 6

AVERAGE JOURNEY TIME FOR ROAD COMMUTERS TO LONDON
(EXCLUDING WALKING AND WAITING TIMES)
POSSIBLE CHANGES IN VEHICLE DESIGN

The formula throws little direct light on the possible changes in vehicle design that would enable more vehicles to use a town centre, but it should be pointed out that, in deriving it, an empirical relationship was used for the capacity of a single road. It is possible that capacities might be increased, possibly very greatly, by changes in vehicle design – smaller vehicles, greater power-weight ratios, especially for heavy vehicles, devices enabling vehicles to travel much closer in safety, etc. In view of the considerable distances between vehicles now necessary for vehicles travelling in line ahead, the latter might enable greatly increased capacities to be achieved. Greater vehicle occupancies would, of course, also help materially. This subject is discussed in the Ministry of Transport’s publication *Cars for Cities* (page 93), which, however, concluded that the automatic control necessary has a most important limitation: that the system would not only need to be reliable, but would also have to create a safe situation if it broke down. The Committee saw “the main purpose of vehicle guidance in towns as being to enable vehicles to be driven safely in very narrow lanes”. It is possible, however, that the Committee was unduly pessimistic about the use of devices for shortening the headway between vehicles.
THE ROAD

I have discussed some aspects of the use of vehicles. I shall now consider some aspects of the road system and of the way it is used. The formula suggests that the number of vehicles that can enter an urban road system per hour and travel at, say, 10 miles per hour is equal to $63 \frac{J}{A^4}$, where $J$ is the measure of the efficiency with which the road system is used for commuter traffic. We found no town centre in which $J$ is higher than 46 per cent, and in some cases it seems to be as low as 23 per cent. There are good reasons for this. Inbound traffic in the morning and outbound traffic in the evening often use different parts of the carriageway, so that it is not fully used in either peak period. There are often considerable numbers of parked vehicles present on the roads, and minor roads are used less effectively than major ones. Also the capacity of the streets is sometimes reduced by bottlenecks.

Now, the formula suggests that, to enable one extra commuter vehicle to enter the town centre per hour, we must supply an extra area of road equal to $A^4/63J$ square feet. This requires $A^4/63$ square feet, since we may assume that $J$ is approximately unity for a well designed system of new roads, if tidal movements can be catered for. Taking a peak period of two hours, therefore, it appears that, to enable one extra car to use the road system during this period, we must supply extra road area equal to $A^4/126$ square feet, or $A^4/183$ square feet per commuter if car occupancy averages 1.45. Assuming, as previously, that the area of a town centre is 333 square feet per commuter, this becomes $0.10N^4$ where $N$ is the number of commuters. Thus in a town with 10,000 commuters extra road accommodation can be provided for car drivers by supplying 10 square feet of carriageway per extra car commuter, i.e. 3 per cent of the area per workplace. For a town with 1,000,000 commuters, however, 100 square feet of carriageway must be provided, or 33 per cent of the assumed area per workplace. The cost of road building in urban areas is extremely variable, but for purposes of illustration we can take £10 per square foot, suggesting that in a town with 10,000 commuters we can supply carriageway space for one extra commuter by the expenditure of £100, but in a town with 1,000,000 commuters the cost would rise to £1,000. It is much cheaper to meet traffic requirements in small towns than in large ones, unless there are special site difficulties. Since motorways give considerably greater capacity than ordinary roads — say twice the flow at three times the speed — there are often advantages in using them instead of ordinary new roads.

Improvements at Junctions

It is, however, worth while to consider other methods of increasing capacity. At a junction, the portion of carriageway common to the various roads is in use by the traffic on any one of the roads for only a fraction of the time. Hence the traffic that each road can carry is reduced well below the amount it could take if this difficulty at intersections did not occur. If we could raise the capacity of junctions to that of the roads leading to them there would be a material increase in the traffic capacity of our cities. There are a number of ways in which this might be done. From the purely traffic point of view, the best is to take one road over the other by means of a flyover or underpass, and this need not take the large amount of land that is sometimes suggested. The large area required for some interchanges is due to the turning sections they contain being made suitable for high speeds. But, in fact, the extra
length they contain often makes the time taken through them longer than they would be if the speeds were lower.

A second way is to widen the road in the neighbourhood of the intersections. A calculation suggests that the capacity of the London road network [9] might be increased by 50 per cent by enlarging the 200 controlled intersections within 2 miles of Charing Cross. The area involved would be 90 acres, and the area of new carriageway per extra commuter would be 34 square feet instead of the 96 square feet required for building ordinary roads (see Appendix 7).

Use of Ring Roads round a Central Area

Another technique which can be used to increase the number of vehicles that can use a town centre is to build a ring road round it, which vehicles can use to minimise their distance travelled within the town centre. Figure 8 gives the results of calculations for an idealised network in a circular town centre in which destinations are uniformly distributed. If vehicles arriving at the outskirts of such a town centre drive along the radial leading from the point of arrival until they reach the concentric circular road on which their destinations lie, and then travel along this road until they reach their destinations, the average distance travelled is $0.78A_1$, where $A$ is the area of the town centre. If, on the other hand, they drive along a ring road round the town centre until they reach the radial on which their destinations lie, the total distance travelled is $1.07A_1$ but the distance within the town centre falls to $0.19A_1$, i.e. the total distance travelled rises by 38 per cent but the distance within the town centre falls by 76 per cent.

Figure 9 gives the results of similar calculations for two real networks in which it has been assumed that origins are equally distributed at the points at which the roads meet the boundaries of the network and that destinations are uniformly distributed along the sides of the roads.

The average distance travelled within the ring falls by 77 and 78 per cent, whilst the total distance travelled rises by 21 and 31 per cent.

The extra length of road required and the extra total travelling distances will often be justified, since the cost of road building is usually much less on the outskirts of the central area than within it, and because such roads often enable vehicles to travel much faster than on roads within the town centre. They also often have much less harmful effects on the amenities of the town centre. They are, however, likely to involve the building of intersections for large amounts of traffic, and this can cause difficulties.

It should, however, be mentioned that the ring road is not so advantageous for journeys within the town centre, or for large town centres in which there is a tendency for commuters to live on the same side of the town centre as their workplaces. But calculations for London suggest that the reduction in commuter distance travelled within the town centre would be more than 50 per cent.

Parking

It is often stated that car commuting is not possible because of the difficulty of providing car parks in our crowded cities. It is, therefore, worth while to examine this. Measurement shows that car parks usually require about 250 square feet per car. At an average car occupancy of 1.45 persons, this is equivalent to about 172
**Fig. 8**

**DISTANCE TRAVELLED ON SOME IDEALIZED NETWORKS**

<table>
<thead>
<tr>
<th>Network Type</th>
<th>Average distance travelled/$A^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radial arc network</td>
<td>Total 0.78</td>
</tr>
<tr>
<td></td>
<td>Within town centre 0.78</td>
</tr>
<tr>
<td>Ring road + radials</td>
<td>Total 1.07</td>
</tr>
<tr>
<td></td>
<td>Within 0.19</td>
</tr>
</tbody>
</table>

**Fig. 9**

**DISTANCE TRAVELLED ON TWO REAL NETWORKS**

<table>
<thead>
<tr>
<th>Network Type</th>
<th>Average distance travelled/$A^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cambridge</td>
<td>Without ring road 0.86</td>
</tr>
<tr>
<td></td>
<td>Total with ring road 1.13</td>
</tr>
<tr>
<td></td>
<td>Within ring road 0.20</td>
</tr>
<tr>
<td>Northwood</td>
<td>Without ring road 1.06</td>
</tr>
<tr>
<td></td>
<td>Total with ring road 1.28</td>
</tr>
<tr>
<td></td>
<td>Within ring road 0.23</td>
</tr>
</tbody>
</table>
square feet per commuter. In a six-storey car park, this amounts to about 29 square feet of ground space per commuter, or about 9 per cent of the ground space in a town centre with the average workplace density of Central London. The proportion would, of course, be much higher in some parts of London, but much less in others, and it could be smaller if higher car occupancies could be achieved.

It is worth noting that the area of car park occupied by cars is about 30 per cent of the total area used, and that it should be possible to use the area much more effectively if car and car park designers turned their attention to ways of making this possible.

It should, however, be mentioned that the recent report *Cars for Cities*, already referred to, thought that the possible savings were small. It states (page 141): “Street parking might be easier if cars could be moved bodily sideways, or could pivot about one end...[and] if all cars were to be so designed perhaps 10-15 per cent more cars could be parked against the kerb by this means...We doubt whether the saving in parking space would justify the cost of equipping cars to manoeuvre in this way”. Again (page 15): “Unorthodox car designs do not seem likely to contribute very much to saving parking space, even assuming that most car users were prepared to accept them”. The kind of devices referred to would enable vehicles to be parked closer to the kerb and to the sides of home garages and would enable many more vehicles to be parked in car parks of given dimensions. The savings in car parks would be expected to be appreciably greater than 10-15 per cent. The matter clearly needs more examination than is given in the report. There are, of course, other parking difficulties which also need to be tackled, such as the difficulties due to large numbers of people trying to enter or leave the car park at about the same time.

THE POSSIBILITY OF A MARKED IMPROVEMENT IN TRAFFIC CONDITIONS

We have now considered some possible changes in both vehicles and roads. It is clear that both have a major part to play in enabling us to travel under more pleasant conditions than we do now and in the general improvement of the environment in which we live. But it is clear that the changes required for a really major improvement in conditions are going to take a long time. Some of them require the absorption of very considerable amounts of money and of civil engineering resources. Others require the use of technologies not yet developed. Meanwhile the amount of traffic is growing rapidly. We should consider whether anything can be done in the more immediate future. But before I do this I wish to consider a fundamental question. Will it ever be possible to solve the problem completely? If we improve our vehicles so that more of them can use a given amount of road space, and/or if we increase the road area available, the result could be an increase in travel speed, or a shortening of the peak travel period, or an increase in the number of commuters, or a combination of these. Since there are advantages in having a much shorter peak travel period than two hours, and since there is a great deal of pent-up demand for more road travel facilities in our larger towns, a conceivable result of quite a considerable improvement in vehicles and in road building might well be the same speeds as we have now.
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It is desirable to consider the question quantitatively, and I will make use of some traffic counts made by the Metropolitan Police periodically since 1904 at an increasing number of points in London. Unfortunately it has not been possible to obtain some of the details of the earlier counts, but Table 10 gives the ratios of the numbers of vehicles passing through various intersections in Central London in 1966 and 1904.

### Table 10

*Increase in traffic in Central London (1904-1966) 8 a.m.-8 p.m.*

<table>
<thead>
<tr>
<th>Intersection</th>
<th>Total traffic 1966*</th>
<th>Total traffic 1904</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bank of England junction</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Cheapside—Newgate Street</td>
<td>1.6</td>
<td>1.6</td>
</tr>
<tr>
<td>Queen Victoria Street—Cannon Street</td>
<td>1.6</td>
<td>1.6</td>
</tr>
<tr>
<td>Holborn Circus</td>
<td>1.7</td>
<td>1.7</td>
</tr>
<tr>
<td>Cornhill—Bishopsgate</td>
<td>2.1</td>
<td>2.1</td>
</tr>
<tr>
<td>Blackfriars Bridge—Victoria Embankment</td>
<td>2.3</td>
<td>2.3</td>
</tr>
<tr>
<td>Piccadilly Circus</td>
<td>2.4</td>
<td>2.4</td>
</tr>
</tbody>
</table>

*Total number of vehicles, including pedal cycles, passing through the intersection

It will be seen that in this period of 62 years, a period in which the number of motor vehicles in Great Britain has increased from 18,000 to 13 million, the amounts of traffic at these points increased by a factor of 2.4 or less, although, of course, in the intervening period horse-drawn vehicles have more or less disappeared and the numbers of pedal cycles have been much reduced. This suggests that there is a large amount of traffic that would like to travel in Central London but is held back by congestion. A comparison of the increases in motor traffic is possible since 1925, and this is given in Table 11.

### Table 11

*Increase in motor vehicle traffic 1925-1966*  

<table>
<thead>
<tr>
<th>Distance from Charing Cross (miles):</th>
<th>Motor vehicles 1966</th>
<th>Motor vehicles 1925</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 2</td>
<td>2.2</td>
<td>3.0</td>
</tr>
<tr>
<td>2—4</td>
<td>3.3</td>
<td></td>
</tr>
<tr>
<td>4—6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>More than 6</td>
<td>5.1</td>
<td></td>
</tr>
<tr>
<td>Motor traffic on trunk and Class 1 roads</td>
<td></td>
<td>10</td>
</tr>
</tbody>
</table>

\[
\text{Licensed motor vehicles 1966} = 8.5 \times \frac{\text{Licensed motor vehicles 1925}}{\text{Licensed motor vehicles 1925}}
\]

*The ratios in the table are obtained by finding for each zone the geometric means of the ratios of the numbers of motor vehicles passing those points common to successive censuses, and multiplying these mean ratios together.

*Note. During the period 1921-1961 the working population of inner London—City, Finsbury, Holborn, Marylebone and Westminster—increased by 13 per cent.*

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Table 11 shows that during this period motor traffic in the country as a whole has increased to about ten times its 1925 value, whilst in Central London it has increased to only 2.2 times its earlier value. Thus, if it were not for the inhibiting effects of congestion, we might well have 4 to 5 times as much traffic in Central London as we have now, quite apart from the likelihood that congestion has limited the numbers of workers.

But not only is there a great deal of frustrated traffic; the amount of traffic in the country as a whole is increasing rapidly. Figure 10 shows the estimated annual mileage of motor vehicles on urban roads since 1956, the first year for which satisfactory data are available, together with the numbers of licensed motor vehicles each year since 1946. Both are shown on a logarithmic scale. The number of licensed motor vehicles has been increasing at a fairly steady rate, averaging 7½ per cent per year compound for 20 years, and there is no certain sign of this rate of increase slackening off, although it must do so eventually.

We must, however, expect the number of licensed vehicles in Britain, now 0.24 per head, to approximate in the foreseeable future to the present U.S. figure of 0.49 per head, which is itself increasing. This result will occur in ten years if present growth rates continue. This is unlikely, but we must clearly envisage a doubling of the number of licensed motor vehicles in the not distant future, say between 10 and 20 years from now.

Fig. 10

TRENDS IN TRAFFIC AND LICENSED MOTOR VEHICLES
TRAFFIC STUDIES AND URBAN CONGESTION

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The figure shows that during the period for which data are available the distance travelled each year by motor vehicles in both rural and urban areas has been approximately proportional to the number of motor vehicles licensed, so that we must expect a doubling of the amount of traffic desiring to enter city centres during this period. (The explanation of the paradox that traffic in some city centres has increased little, whereas traffic in urban areas as a whole is increasing at 7½ per cent per year compound, is that traffic in some urban areas – especially some suburban areas – is increasing at a rate greater than 7½ per cent, and that the vehicle-mileage in town centres is only a small proportion of total urban mileage). The amount of traffic that desires to travel in Central London could therefore increase from the present figure of 4 to 5 times the existing traffic to 8 to 10 times the existing traffic in the next few years. Although many knowledgeable people would not agree with me, I think it conceivable that road capacity in city centres might eventually be increased by this amount by the kinds of changes in roads and vehicles I outlined earlier, but there is no possibility whatsoever of this occurring within the next ten to twenty years. But even this does not represent the amount by which road capacity must be increased to enable traffic to move at moderately high speeds in Central London. This is so for two major reasons:

(i) The calculation starts with the base year 1925, in which Central London was already congested.

(ii) The peak travel period has its present value because of the congestion. Except for this the present peak period of (say) two hours would certainly be less, possibly one half or one quarter its present duration.

It seems therefore that to meet the potential demand for traffic capacity in Central London with a short peak traffic period might well necessitate an increase of road capacity to at least 20 times its present value. It is very difficult to envisage the possibility of achieving this in London; even in smaller towns, where so large an increase would not be required, there would clearly be difficulties. It may well not be possible to design a transport system for a large town in which everybody can travel at high speed during a short peak travel period. This conclusion probably applies to people travelling by car, by bus, by train or by some new vehicle not yet invented. (This is because the capacity required of a transport system to meet the demand can be expressed as the ratio of the number of persons to be transported to the duration of the peak travel period. If, therefore, the peak travel period is sufficiently short the capacity required will be higher than any given capacity.)

We thus see that:

(i) There is a definite limit to the number of vehicles that can travel in a town centre in a given time. This limit can be made higher, possibly very considerably higher, by various means, but this is bound to take many years, at least as far as the larger towns are concerned.

(ii) Because of the limited capacity of the road networks, many vehicles both private and commercial are already prevented by congestion from using town centres during peak travel periods.

(iii) The use of congestion as a means of limiting the amounts of traffic results in low speeds. The speed of traffic could be raised appreciably at places where it is now very low by a small decrease in the amount of traffic. For
example, at a place where the speed of traffic is 6 miles per hour, the removal of 10 per cent of the traffic would raise the speed to 11 miles per hour. If the speed is 11 miles per hour, the removal of 10 per cent would raise it to 13 miles per hour.

(iv) It would be difficult to achieve a large reduction in traffic in large towns by banning particular classes of vehicles, since this would merely encourage other traffic now removed by congestion.

A number of economists have suggested that people should be charged for the congestion they cause [10]. This might get round the fundamental difficulty by discouraging some people from travelling during congested periods and so raising the speed of those that remain. It is not necessarily suggested that motorists should pay more in total taxation. The suggestion is that other forms of motor taxation should be reduced, although it is inevitable that some would pay more than they do now while others would pay less. There are, I believe, four main arguments put forward against the proposal, as follows:

The first argument is that it is impossible to devise satisfactory methods of charging and/or that these methods would be costly. I find it difficult to believe that modern technology could not produce satisfactory methods, and their expense must be weighed against the advantages.

The second argument is that it is unfair. The rich would be able to travel by car, the poor would not. This is really an argument against the present methods of allocating incomes, and we use the price mechanism to allocate far more essential items than vehicle usage in towns. In any case, the present methods of allocating road space in towns might reasonably be regarded as unfair. Now we allocate it to the people who are prepared to spend a great deal of their time in traffic queues, not necessarily to the people who need it most.

The third argument is that charging for road usage in this way is just another tax on the motorist and that the government would not reduce other motor taxes to balance the money it received from a congestion tax. I have a great deal of sympathy with this argument.

The fourth argument is that the charges necessary to deter people would be so high as to make the whole scheme impracticable. There are, however, indications from a number of sources that this may not be so. For example, a number of investigations have been made, including one involving the staff of this College, in which the time that would be saved by the travellers changing to another mode of travel

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<td>Greater than 9</td>
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</table>
TRAFFIC STUDIES AND URBAN CONGESTION

R. J. Smeed

has been compared with the extra cost of doing so. Nearly all these investigations suggest that – on the average – people value their travelling time at rather less than half their wage rate.

Another indication of possible effects of charging for road use is the fact that low income groups travelling to work by car during peak travel periods tend to have higher car occupancies than high income groups. Some results for St. Louis, U.S.A., are given in Table 12.

It is clear that investigations into the likely gains and losses from a pricing system are very desirable.

CONCLUSIONS ON URBAN CONGESTION

My own conclusion from the facts and figures I have put before you is that, if people wish to travel at considerably higher speeds in our town centres during peak travel periods, it will be necessary to increase the efforts now being made to improve the road system and to make a more conscious effort to improve the vehicle from the road capacity point of view. But these steps will not be enough for the large towns. One suggestion that has so far been put forward, but has not yet been tried, is to charge people for the congestion that they cause. This might result in greater use of public transport or in encouraging greater occupancy of private cars, or both. If lower tariffs were charged at non-peak hours, it might encourage longer peak travel periods. It might cause a partial redistribution of homes and workplaces. If these effects occurred they could have a major effect on urban traffic congestion. It would not be a substitute for road and vehicle improvements, but it might be a valuable supplement. One alternative is a redistribution of homes and workplaces – including making towns smaller or at least having smaller town centres – if methods of achieving this other than by charging for road use can be found.

THE STRATEGY FOR DEALING WITH ROAD TRAFFIC PROBLEMS

I have taken just one example of a traffic problem and have – I believe – shown that quantitative reasoning can usefully be applied to give us an understanding of the subject and to assess the likely effects of some of the measures that might be directed to lessening the difficulties. It became obvious during the analysis that on almost every aspect of the subject there are major questions affecting the life and welfare of the community to which we have not yet got answers. For example, we do not know the answer to the quite fundamental question of what happens when restrictions are placed on the use of vehicles, such as what proportions of travellers would change to public transport and what proportions would give up making the journey. A similar lack of adequate knowledge would have been revealed if I had discussed the amenity or accident problems caused by traffic, or almost any other traffic problem. We know quite a lot about them but not nearly enough. It is, I believe, certain that answers to many of these questions can be obtained, and that it can be done without enormous effort, provided that sufficient resources of money and qualified people are available. It seems to me that the universities might well play a major part in finding the answers to these questions and in training the
students who later on will apply the answers found. The problems are challenging
and many of them are of intellectual interest; their solutions require the same kinds
of techniques as are used in a wide variety of the problems tackled at universities.
The problems are of concern to almost everybody. Traffic is, I suspect, discussed as
frequently as the weather, or sometimes even more. On the continent of Europe and
in the U.S.A. the universities have taken a major interest in the subject, but, relatively
to some other countries, universities here have put only a small effort into research
in this field, although they have made some outstanding contributions. This college
was one of the first to take an interest in traffic: Hounsfield, of the Civil Engineering
Department, did important work as early as 1949. I hope that the universities will,
in future, be able to make many significant contributions.

ACKNOWLEDGEMENTS

Data have been kindly supplied by many highway and other authorities, too
numerous to mention. They can, to an appreciable extent, be deduced from
the names of the towns from which data are quoted. Without their help much of the
work described in this paper would not have been possible. I am most grateful to
them for their assistance.

I am also indebted to the members of my Traffic Studies Group for their help in
preparing various parts of this paper.

REFERENCES

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Connecticut.
of cars and buses for travel in urban areas. J. Inst. Transp., 1964, 30 (9), 301-5.
# Some basic data relating to town centres

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<th>Speed (mile/h)</th>
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<td>(F)</td>
<td>(Q)</td>
<td>(c)</td>
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</table>

\[\text{\textdagger}\text{Crossing cordon in peak direction.}\]

*Data on flows obtained from the Road Research Laboratory.

Data on flows for St. Helier were collected by the Geography Dept., University College, London, and other flows were obtained from authorities concerned, usually the highway authorities.

The area of carriageway and the area within the cordons were obtained either from maps or again from the authorities concerned.

The speeds marked $ were obtained by a colleague of the writer, making a journey lasting about three-quarters of an hour in the town concerned. Other speeds were obtained from the highway authorities concerned.
APPENDIX 2

The Relationship between Increases in Traffic and Increases in the Time Loss due to Congestion

The paper shows that the relationship between the average speed of traffic \( v \) and its amount \( q \) may be expressed approximately by an equation of the form

\[
q = a - b \, v^2
\]

or

\[
q = q_0 \left( 1 - \frac{v^2}{v_0^2} \right),
\]

where \( v_0 \) is the speed under light traffic conditions and \( q_0 \) the maximum flow.

Now the time taken for a journey of length \( l \) is \( l/v \) at speed \( v \) and \( l/v_0 \) at speed \( v_0 \). If we define \( C \), the time loss due to congestion, as the difference between the time taken by vehicles when the speed is \( v \) and the time they would take if they could move at the speed of traffic under light traffic conditions, it follows that

\[
C = q \left( \frac{l}{v} - \frac{l}{v_0} \right).
\]

The increase in time loss \( \delta C \) due to an increase in traffic \( \delta q \) is therefore given by

\[
\frac{\delta C}{\delta q} = \left( \frac{l}{v} - \frac{l}{v_0} \right) - \frac{ql}{v^2} \frac{dv}{dq}.
\]

Since

\[
\frac{dq}{dv} = \frac{-2q_0 v}{v^2},
\]

it follows that

\[
\frac{1}{l} \frac{\delta C}{\delta q} = \left( \frac{l}{v} - \frac{l}{v_0} \right) + \frac{q_0 v_0^2}{2q_0 v^3}
= \frac{l}{2v_0} \left( \frac{v_0}{v} - 1 \right) \left( \frac{v_0^2}{v^2} + \frac{v_0}{v} + 2 \right)
\]

Also

\[
\frac{\delta C}{\frac{C}{q}} = \frac{\text{Percentage increase in time loss due to congestion}}{\text{Percentage increase in traffic}}
= \frac{q}{C} \frac{\delta C}{\delta q}
= \frac{1}{l} \left( \frac{v_0^2}{v^2} + \frac{v_0}{v} + 2 \right).
\]

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APPENDIX 3

The Time Losses imposed on other Vehicles by the Introduction of a Single Extra Vehicle into a Traffic Stream

The time \( T \) taken for a journey of length \( l \) is \( l/v \) and the change in time \( \delta T \) due to a small change in speed \( \delta v \) is \( -\frac{l\delta v}{v^2} \).

If the change in speed is due to a small change \( \delta q \) in the flow, then

\[
\delta T = -\frac{l}{v^2} \frac{dv}{dq} \delta q
\]

Hence, the total increase in journey time of other vehicles due to the introduction of one extra vehicle into the traffic stream is \( -\frac{ql}{v^2} \frac{dv}{dq} \), where \( q \) is the flow before the extra vehicle is introduced.

Using as in the previous section the fact that the relation between \( q \) and \( v \) can be expressed in the form \( q = q_0 \left( 1 - \frac{v^2}{v_0^2} \right) \) it follows that the time loss imposed on other vehicles is

\[
\frac{l}{2v} \left( \frac{v_0^2}{v^2} - 1 \right).
\]

Since the time taken for the journey is \( l/v \), it follows that

\[
\frac{\text{Time losses imposed on other vehicles}}{\text{Time of journey}} = \frac{1}{2} \left( \frac{v_0^2}{v^2} - 1 \right).
\]

It is worth while noting that, since the extra time loss on a road due to the introduction of an extra vehicle is equal to the time lost sustained by the vehicle plus the time loss that vehicle causes to others, the formulae obtained in this Appendix and the last one are related. Thus

\[
\frac{l}{2v_0} \left( \frac{v_0}{v} - 1 \right) \left( \frac{v_0^2}{v^2} + \frac{v_0}{v} + 2 \right) = l \left( \frac{1}{v} - \frac{1}{v_0} \right) + \frac{l}{2v} \left( \frac{v_0^2}{v^2} - 1 \right).
\]

APPENDIX 4

The Proportion of Carriageway occupied by Vehicles Entering

The average distance travelled in the town centre is \( 0.87A^4 \) feet, and at a speed of \( v \) miles per hour the journey takes an average time \( \frac{0.87A^4}{5280v} \) hours approximately. The number of car equivalents that can enter (or leave) the town centre during this time is...
approximately, and this is the number of car equivalents travelling within the town centre at any moment. The average car occupies about 70 square feet in plan area, and the plan area (in square feet) occupied by vehicles within the town centre is therefore 70 times the above expression, assuming that the average area occupied by a vehicle of a given type is proportional to its car equivalent. Since the area of carriageway is $fA$, the fraction of carriageway occupied at any moment by vehicles which have entered is

$$\frac{0.87 \times 70 (36 - 0.069e^2)}{5280}$$

**APPENDIX 5**

**Derivation of Table 9**

*Car Travel*

The number of car equivalents that can circulate in a town centre at 9 miles per hour is $30fA^\frac{1}{2}$ per hour.

If $N$ is the number of workplaces and $G$ is the average area per workplace, then $A = NG$ and the number of cars that can reach their destinations in a peak period of $T$ hours is

$$30fT(NG)^\frac{1}{2}$$

If 30 per cent of the traffic, measured in car equivalents, is non-passenger-carrying vehicles, then the car equivalent of the passenger-carrying vehicles is 70 per cent of this figure.

If all passenger vehicles are cars with an average occupancy $e$, the number of commuters that can reach their destinations by car is $e$ times the above figure.

Then the proportion of commuters that can enter by car is

$$21feT\left(\frac{G}{N}\right)^\frac{1}{2}$$

All commuters can enter by car if this proportion is at least unity, *i.e.* if

$$N < 441.25e^2T^2G$$

*Bus Travel*

To estimate the number of commuters that can enter by bus, we must make allowance for the facts that a bus is – at any rate in Central London – the equivalent of 3 cars, as far as road capacity is concerned, that a bus travels right across the town centre and that it usually travels by less direct routes. Taking a sector of the town centre whose apex is on the cordon bounding it, the average distance of all destinations assumed uniformly distributed from the apex is two-thirds of the length of the sector.
Hence a bus travelling right across the central area would travel a distance 50 per cent greater than the average distance travelled direct to destinations. In addition, investigations in London showed that bus distance travelled for a single journey averages 6 per cent more than that of cars. Hence, the average distance travelled by a bus in a town centre is about $1.50 \times 1.06$ times that travelled by car. The main paper assumes that cars travel a distance $0.87A^H$ within the town centre. Hence buses must be assumed to travel a distance $1.06 \times 1.5 \times 0.87A^H = 1.38A^H$. Using the expression given in the paper for the width of road required by a bus, it follows that the area of road required by $q$ buses per hour is

$$\frac{4.14A^Hq}{68 - 0.13v^2}$$

The total area of carriageway available if all the effective road space is used is $JfA$, of which 30 per cent is used for commercial traffic. Hence, assuming $J = 0.46$, as for cars, we get

$$Q = (5.3 - 0.010v^2)fA^H$$

$$= 4.49fA^H,$$

when $v = 9$ miles per hour.

The proportion of commuters that can reach their destinations by bus becomes

$$4.49feT\left(\frac{G}{N}\right)^H,$$ 

where $e$ is now the bus occupancy at the cordon.

All the commuters can enter by bus if

$$N < 20.2f^2e^2T^2G$$

**APPENDIX 6**

**Times of Journeys**

The average distance travelled by a car within the town centre is $0.87A^H$ feet. Since the speed is $v$ miles per hour, the total time taken for a journey within the town centre is

$$\left(\frac{0.87A^H}{v \times 88} + \tau_c\right)$$

minutes where $\tau_c$ minutes is the time taken for parking and unparking and for walking between the car park and workplace.

Assuming that the length of a bus journey is six per cent longer than that of a car journey because buses tend to travel by less direct routes, and that buses require $1\frac{1}{2}$ minutes per mile [12] for taking up and setting down passengers, the journey time for a bus passenger is

$$\left(\frac{1.06}{88} \times \frac{0.87A^H}{v} + \frac{1.5 \times 0.87A^H}{5280} + \tau_b\right)$$

minutes,

where $\tau_b$ minutes is the time spent waiting at bus stops and walking between bus stops and destinations.
January 1968

Let $p$ be the fraction of commuters that travel by car. Then the number of car journeys is $\frac{pN}{c}$ and the number of bus journeys is $\frac{(1-p)N}{c'}$ where $c$ and $c'$ are the average occupancies of cars and buses respectively. The distance travelled by cars is therefore $\frac{pN}{c} \times 0.87A^1\frac{1}{T}$ and by buses $\frac{(1-p)N}{c'} \times 0.87A^1\frac{1}{T} \times 1.5 \times 1.06$.

It is shown in the paper that the area of carriageway required may be obtained by assuming that during its travel a car requires a width of road $\frac{1}{T(68 - 0.13p^2)}$ feet, for a journey during a peak period $T$ hours, and that a bus requires three times this quantity. Assuming that all the travel takes place in a peak period and that a proportion $\gamma$ of the available carriageway must be left for commercial vehicles, and that a proportion $f$ is used effectively, it follows, by equating the road area required with the available road area, that

$$
\left( \frac{pN}{c} \times 0.87A^1 + \frac{(1-p)N}{c'} \times 0.87A^1 \times 1.5 \times 1.06 \right) \left( \frac{1}{68 - 0.13p^2} \right) = JT(1 - \gamma)fA
$$

Putting $A = NG$, we get

$$
v^2 = 523 - 6.69 \left( \frac{N}{G} \frac{\frac{p}{c} + \frac{4.77(1-p)}{c'}}{(1 - \gamma)fT} \right) \left( \frac{NG}{523} \right)
$$

$$
v = \sqrt{523 - 6.69 \left( \frac{N}{G} \frac{\frac{p}{c} + \frac{4.77(1-p)}{c'}}{(1 - \gamma)fT} \right) \left( \frac{NG}{523} \right)}
$$

and average time for car journeys in the town centre becomes

$$\frac{0.87(NG)^{\frac{1}{2}}}{2013\sqrt{1 - 6.69 \left( \frac{N}{G} \frac{\frac{p}{c} + \frac{4.77(1-p)}{c'}}{(1 - \gamma)fT} \right) \left( \frac{NG}{523} \right)}} \text{ minutes}
$$

$$= \frac{0.000432(NG)^{\frac{1}{2}}}{\sqrt{1 - 0.0128 \left( \frac{N}{G} \frac{\frac{p}{c} + \frac{4.77(1-p)}{c'}}{(1 - \gamma)fT} \right) \left( \frac{NG}{523} \right)}} \text{ minutes.}$$
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If $c = 1.45$, $c' = 42.5$, $f = 0.14$, $T = 2$, $J = 0.46$, $\gamma = 0.3$ this becomes

$$\frac{0.000432 \ (NG) \frac{1}{4}}{\sqrt{1 - \left(\frac{N}{G}\right) \frac{1}{4} \ [0.0821 \ p + 0.0159]}}$$

The maximum number of commuters that can enter a town centre can be found by putting $v = 0$ in the above expression. Hence this number is given by

$$\left(\frac{N}{G}\right) \frac{1}{4} = \frac{523 (1 - \gamma) J f T}{6.69 \left[ \frac{p}{c} + 4.77 \left(\frac{1 - \lambda}{c'}\right) \right]}.$$

Assuming as above that $J = 0.46$, we get

$$N = \frac{1300 (1 - \gamma)^2 f^2 T^2 G}{\left[ \frac{p}{c} + 4.77 \left(\frac{1 - \lambda}{c'}\right) \right]^2}.$$

APPENDIX 7

Extra Capacity of Road Network obtained by enlarging Intersections

It is shown in [9] that the capacity of the road network within two miles of Charing Cross could be enlarged by 50 per cent by enlarging 200 intersections, involving the use of 90 acres of land.

Now the existing capacity of the network is given by the formula, and, assuming a speed of 9 miles per hour, a fraction 0.14 of the area devoted to roads and a two-hour peak travel period, the capacity is $2 \times 30 \times 0.14 \times (\pi \times 10,560^2)^{\frac{1}{2}} = 157,000$ car equivalents.

Hence the capacity of the network would be increased by 78,500 car equivalents by the use of 90 acres of land.

Hence, the area of new carriageway per extra commuter would be

$$\frac{90 \times 4840 \times 9}{78,500 \times 1.45} = 34 \text{ square feet}.$$

This result can be generalised if it is assumed that the number of major intersections in a town centre is proportional to the area $A$ of the town centre. It then follows that the number of major intersections in the town centre is

$$\frac{200 \ A}{4\pi \times 5,280^2} = 0.571 \frac{A}{10^6}.$$
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To increase the capacity by 50 per cent requires that each should have an additional area \( \frac{90}{200} \) acres = 19,600 square feet.

This would increase the capacity of the system by \( 0.5 \times 30.4 \times A^\frac{1}{4} \) p.c.u.s per hour = \( 4.26 \times A^\frac{1}{4} \) p.c.u.s in two hours = \( 4.26 \times 1.45 \times A^\frac{1}{4} = 6.18 \times A^\frac{1}{4} \) commuters in a two-hour peak period.

Hence the capacity of the system for a two-hour peak period could be increased by one extra car commuter by the use of \( \frac{0.571 \times 19,600}{10^6 \times 6.18} \times A^\frac{1}{4} \) sq. ft. = \( \frac{1.81 \times A^\frac{1}{4}}{10^3} \) sq. ft.

\[ \frac{1.81 (NC)^\frac{1}{4}}{10^3} = \frac{1.81 \times 333^\frac{1}{4}}{10^3} \cdot N^\frac{1}{4} = \frac{N^\frac{1}{4}}{30} . \]