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ASSESSING THE EFFECT OF TRAFFIC CONGESTION ON MOTOR VEHICLE FUEL CONSUMPTION

by

L Gyenes BSc

Assessment Division
Transport Systems Department
Transport and Road Research Laboratory
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ABSTRACT

This report estimates the part of the UK road transport fuel consumption which is due to traffic congestion. The assessment is based on past surveys of journey speeds in towns, conurbations and Greater London together with data relating fuel consumption to average speed.

The estimated potential saving in the use of road transport fuel if traffic congestion could be reduced from peak to off-peak conditions with the same number of vehicle journeys is 1.5 per cent. A further saving of 4.6 per cent would be achieved if it were possible to reduce off-peak traffic conditions to ideal 'free-flow' traffic conditions with an average traffic speed of 50 km/h. These comparatively small savings reflect the small amount of driving that takes place in congested areas over the whole country.

1. INTRODUCTION

The aim of this study is to identify the part of the UK road transport fuel consumption which is due to traffic congestion, and could therefore be reduced by measures which modify traffic flows.

Motor vehicle fuel consumption studies show[1,2,3,4] that obstructions to constant speed driving such as road junctions, roundabouts, traffic lights, pedestrian crossings, parked and moving vehicles are the main causes of energy consumption additional to those needed to propel the vehicle at steady speed. Fuel consumption over urban roads is higher than fuel consumption over all purpose rural roads[1], because obstructions to traffic flow occur more frequently in built-up areas than in rural areas of the country[5]. Observed low average speeds and high fuel consumption are often attributed to the movement of other vehicles on the road, that is, to 'traffic congestion'. However, such higher fuel consumption can only partly be due to the higher volumes of traffic found on urban roads: other factors of road geometry will also affect the fuel used.

In this study survey data on journey speeds and flows from UK towns and conurbations have been used to isolate the effect on fuel consumption of traffic congestion from road geometry. The large change in traffic volume which occurs between off-peak and peak periods of travel provides the right data for this purpose, together with data on fuel consumption and journey time[1]. Because traffic congestion is mainly confined to urban roads, the investigation applies to motor vehicles travelling in built-up areas, which accounts for 50 per cent of total annual motor vehicle travel in the United Kingdom[6].

2. METHOD OF ASSESSMENT

TRRL has carried out surveys[7,8,9] of journey speeds and flows on all main roads in principal cities of five conurbations outside London (population range 300,000 to 1,100,000) and eight towns (population range 80,000 to 560,000). Similar surveys were carried out over the Greater London area by the Greater London Council[10,11]. This data together with data relating fuel consumption to average speed[1] is used to estimate the proportion of car travel at each different fuel consumption during peak and off-peak periods of travel in built-up areas in the United Kingdom. By definition, all roads with 48 km/h (30 mph) or 64 km/h (40 mph) speed limits are 'built-up area' roads regardless of their location. However, the majority of roads with these speed limits are located in built-up areas.

Assuming that the off-peak traffic flow represents conditions of free-flow on the road network, the difference in mean fuel consumption between off-peak and peak periods of travel provides an estimate for the lower limit of fuel consumption due to traffic congestion. An estimate for the upper limit of fuel consumption, due to traffic congestion, is obtained by adding the increase in mean fuel consumption between ideal 'free-flow' and off-peak travel to the already calculated difference between off-peak and peak periods. The ideal 'free-flow' travel speed is assumed to be 50 km/h. This is a plausible upper limit for average speed, which it is just possible to achieve on some routes in built-up areas under traffic free conditions. The majority of general purpose roads in built-up areas are limited to 48 km/h (30 mph) speed, very close to the figure chosen. Furthermore, the observed highest off-peak average speeds in the survey areas are just within the ideal 'free-flow' limit, at which speed, fuel consumption is lowest in built-up areas[1].

3. FUEL CONSUMPTION AND JOURNEY TIME RELATIONSHIPS

At low average speeds of 10–35 km/h, fuel consumption and journey time (the inverse of average speed), measured over road sections of 1–5 km in length in built-up areas and averaged in both directions of travel[1], show linear correlation in Figure 1. The best fit relationship for cars, light and heavy commercial vehicles are listed in Table 1. The surveyed road sections included heavily trafficked areas of Central London, suburban residential streets, urban traffic arteries, small towns and 64 km/h (40 mph) speed restricted main roads. The relationships listed in Table 1 are assumed to be representative of three broad classes of vehicles and of the average driver.

4. THE EFFECT OF TRAFFIC FLOW ON AVERAGE SPEEDS

Study of average passenger car speeds in Greater London, in eight towns and five conurbations indicate around 30 per cent decrease in average speeds between off-peak and peak periods of travel. Figure 2 and Figure 3 show the proportion of passenger-car-kilometres of travel at different average speeds during peak (7.45–9.15 am, 4.45–6.15 pm) and during off-peak periods (10.30–12.00 am, 2.00–3.30 pm). Apart from traffic volumes (shown in Table 2), parking densities and traffic compositions also change between these two periods. The effects of change in traffic composition, shown in Table 3A and Table 3B, are equivalent to around 25 per cent reduction in the difference between off-peak and peak period traffic volumes. This is due to the higher proportion of commercial vehicles during off-peak travel, the heaviest of which are equivalent to 2–3 passenger cars[12]. Studies[12] suggest that the parking densities, shown in Table 4, are likely to have a negligible effect on journey times.

Differences in driver behaviour, changes in traffic management schemes and changes in the use of bus lanes between peak and off-peak periods are assumed to have negligible effect on journey times.

5. THE EFFECT OF TRAFFIC FLOW ON FUEL CONSUMPTION

The proportions of passenger-car-kilometres of travel at different fuel consumption during peak and off-peak periods have been calculated from the data shown in Figures 1–3 and are shown for Greater London in Figure 4, for towns and conurbations in Figure 5. The variations in the amount of fuel used and mean consumption per vehicle between central and outer areas during different travel periods are shown in Tables 5 and 6. It is evident from these Tables that the estimated 11.0 per cent change in mean fuel consumption per vehicle per hour between off-peak and peak periods of travel in the Greater London area, and the estimated 8.6 per cent change in mean fuel consumption per vehicle per hour between off-peak and peak periods of travel in towns and conurbations are due in the main to the change in fuel consumption in the non-central rather than central areas. The passenger-car-kilometres in Central London and in central areas of towns and conurbations are less than 10 per cent of the total travel in these areas. But it is in these areas that vehicle fuel consumptions of 13 litre/100 km and over occur. An interesting point is that in Central London (ie City and Westminster) the fuel consumption per vehicle during off-peak periods is in some cases higher than during peak periods of travel.

For Greater London, the increase in fuel consumption per vehicle per hour between the ideal 'free-flow' travel and off-peak travel is 14.7 per cent. For towns and conurbations the corresponding figure is 10.5 per cent.

Trends over several years in the differences between off-peak and peak period mean fuel consumption and between 'free-flow' and off-peak period mean fuel consumption are shown in Figure 6. There is insufficient evidence to determine whether the estimated differences have changed in an orderly and significant way since 1967.

6. POTENTIAL FOR FUEL SAVINGS

During weekday busy periods (which include the peak periods 7.45–9.15 am, 4.45–6.15 pm and periods 9.15–10.30 am, 3.30–4.45 pm with volumes of traffic intermediate between peak and off-peak volumes), the total travel is 2/5th of the annual total travel in built-up areas[13]. For the sake of simplicity it is assumed that the average fuel consumption for the whole busy period is the same as the consumption in peak periods that has been estimated so far. Hence if traffic congestion is reduced to off-peak conditions, the annual saving would be 2/5th of 11.0 per cent, that is 4.4 per cent per vehicle in the Greater London area, and 2/5th of 8.6 per cent per vehicle, that is 3.4 per cent in the towns and conurbations surveyed. If the ideal 'free-flow' conditions were achieved in these areas during all periods, the saving per vehicle per annum would be 14.7 plus 4.4 per cent in the Greater London area and 10.5 plus 3.4 per cent in the towns and conurbations.

Taking the lower sets of figures to represent the potential fuel savings in built-up areas, where the fuel used is at least 50 per cent of the annual total of motorway, rural road and urban road fuel usage, the potential for fuel saving through reduction in traffic congestion will be within 1.7 and 7.0 per cent of the total passenger car energy consumption. Using the same principles as above and data given in Tables 1 and 3 together with an estimate for the proportion of fuel used in built-up areas[6], the corresponding figures for light commercial vehicles and heavy commercial vehicles are 1.2 and 5.3, and 0.5 and 2.1 per cent respectively. After allowing for the fuel used by these vehicles[6], the energy saving will be within 1.5 and 6.1 per cent of the total road transport energy consumption.

7. DISCUSSION

It has been shown in the preceeding sections that the effect of traffic congestion on motor vehicle fuel consumption can be assessed on the basis of journey speed survey data and the linear relationship between fuel consumption and journey time (the inverse of average speed). However, traffic surveys have used different sample sizes, different levels of aggregation and different sampling procedures in reaching their conclusions. The effect of these variations on the conclusion about energy consumption needs to be discussed.

All the fourteen surveys used in the present calculations are based on road link by road link surveys of principal roads. In certain cases additional roads were added because of their particular traffic importance. Checks on the influence of additional samples of local roads on traffic area journey times revealed only small inaccuracies due to the sample sizes[14] used (1–2 per cent increase in journey times).

The link by link survey data was aggregated over traffic areas (eg central or non-central areas of towns). The area average speeds (vehicle-kilometres divided by vehicle hours) were then used for calculating the average fuel consumption figures and weighted by the vehicle kilometres of travel area by area. The analysis in the Appendix shows that if the calculations had been carried out road link by road and weighted by the observed link vehicle-kilometres of travel, the same mean fuel consumption would have been obtained as shown in Figures 4 and 5.

Since the completion of this work an altogether different journey speed sampling procedure has been used to assess the effect of traffic congestion on car trip fuel consumption in seven US cities[15]. The trip speeds were obtained by a 'Chase Car' which followed a randomly selected vehicle from start to finish of its normal trip and then followed another vehicle whose trip started at that particular location. If no vehicle started at that location, the next vehicle to drive by was followed. The calculated fuel consumption estimates for each trip were weighted by the trip-kilometres of travel. This technique gave roughly the same estimates for the energy consumption due to traffic congestion in the seven US cities[15] as obtained in this study. The analysis in the Appendix shows that if the random sampling of trips had been carried out over the same urban network as previously, including selection of partial trips whose journey origins and/or destinations lie outside the network, the same mean fuel consumption figures would have been obtained as shown in Figures 4 and 5.

Therefore, the mean fuel consumption figures used in the energy saving calculations can be shown to be unaffected by the level of aggregation in the journey speed data or the sampling procedure used.

8. CONCLUSIONS

1. The increase in traffic congestion between off-peak and peak periods of travel increases aggregate passenger car fuel consumption by 4.4 per cent in the Greater London area and 3.4 per cent in the rest of built-up areas of the country. The calculated increase is based on 1976 survey data of journey speeds and flows. There is insufficient evidence to determine whether the estimated difference between off-peak and peak period fuel consumption has changed significantly over the last decade.

2. The calculated overall increases in fuel consumption between off-peak and peak periods of travel in built-up areas is due in the main to increases in fuel consumption in the non-central areas. Although central area fuel consumption per vehicle is substantially above that in non-central area fuel consumption per vehicle, the amount of travel in central areas is only a small fraction of the total travel, thus making small contribution to overall fuel consumption.

3. The estimated potential saving in the use of road transport fuel through reduction of traffic congestion from peak to off-peak conditions is 1.5 per cent per vehicle per annum. A further saving of 4.6 per cent, making 6.1 per cent in all, might be achieved through reducing off-peak traffic conditions to ideal 'free-flow' traffic conditions with an average traffic speed of 50 km/h. The lower figure of 1.5 per cent provides an estimate of what is practicable to achieve through reduction in traffic congestion; the higher figure of 6.1 per cent sets the upper limit for the total energy consumption due to traffic congestion.

4. The present calculations are based on road link by road link journey speed surveys of principal roads. Checks on the influence of additional samples of local roads revealed only small inaccuracies due to the sample sizes used. The mean fuel consumption figures used in the energy saving calculations can be shown to be unaffected by the sampling procedure (eg link by link or trip by trip sampling) and the level of aggregation used in the journey speed data.

9. ACKNOWLEDGEMENTS

The work described in this report was carried out in the Assessment Division (Division Head: Dr M H L Waters) of the Transport Systems Department of TRRL.

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TABLE 1

Fuel consumption and journey time relationships adopted**

Motor vehicle type	Fuel consumption (F) journey time (T) relationship*
Passenger Car	F = 6.03 + 0.0484T
Light Commercial	F = 8.07 + 0.0427T
Heavy Commercial	F = 23.21 + 0.0625T

* Fuel consumption in litre/100 km
Journey time in seconds/km

** Based on fuel consumption figures of Vauxhall Viva and Ford Zephyr for passenger car, Ford Minibus for light commercial vehicle and a 20 tonne plated weight Leyland lorry for heavy commercial vehicle.

TABLE 2

Average traffic volumes for weekday off-peak and peak periods in built-up areas, 1976

Location	Peak flow (veh/h)	Off-peak flow (veh/h)
Inner London	1900	1360
Outer London	2010	1220
Towns, central area	1570	1190
Towns, non-central area	1490	980
Conurbations, central area	1485	1150
Conurbations, non-central area	1640	1120

TABLE 3A

Weekday off-peak traffic composition in built-up areas, 1976
(Percentage in the traffic stream)

Location	Percentage composition				
	Private cars Taxis	Light commercials	Heavy commercials	Others	All
London	67.3	13.0	15.3	4.4	100.0
Towns	68.5	14.7	12.2	4.6	100.0
Conurbations	66.1	14.4	15.5	4.0	100.0

TABLE 3B

Weekday peak traffic composition in built-up areas, 1976
(Percentage in the traffic stream)

Location	Percentage composition				
	Private cars Taxis	Light commercials	Heavy commercials	Others	All
London	79.0	7.0	9.5	4.5	100.0
Towns	78.8	9.5	5.5	6.2	100.0
Conurbations	79.0	8.9	6.7	5.4	100.0

TABLE 4

Parking densities for weekday off-peak and peak periods in built-up areas, 1976

Location	Peak parking density (veh/km)	Off-peak parking density (veh/km)
Towns, central area	8.8	16.1
Towns, non-central areas	7.0	10.1
Conurbations, central area	5.7	12.5
Conurbations, non-central area	5.0	8.5

TABLE 5

Variation in fuel consumption between Inner London and Outer London in the Greater London area

Area	Peak		Off-peak	
	Fuel used (per cent)	Mean consumption (litre/100 km)	Fuel used (per cent)	Mean consumption (litre/100 km)
Inner London	30.8	13.4	36.0	12.6
Outer London	69.2	11.6	64.0	10.0
Greater London	100.0	12.1	100.0	10.9

TABLE 6

Variation in fuel consumption between central and non-central areas in towns and conurbations, 1976

Area	Peak		Off-peak	
	Fuel used (per cent)	Mean consumption (litre/100 km)	Fuel used (per cent)	Mean consumption (litre/100 km)
Central area	11.6	14.3	13.0	13.4
Non-central area	88.4	11.0	87.0	10.2
Total area	100.0	11.4	100.0	10.6

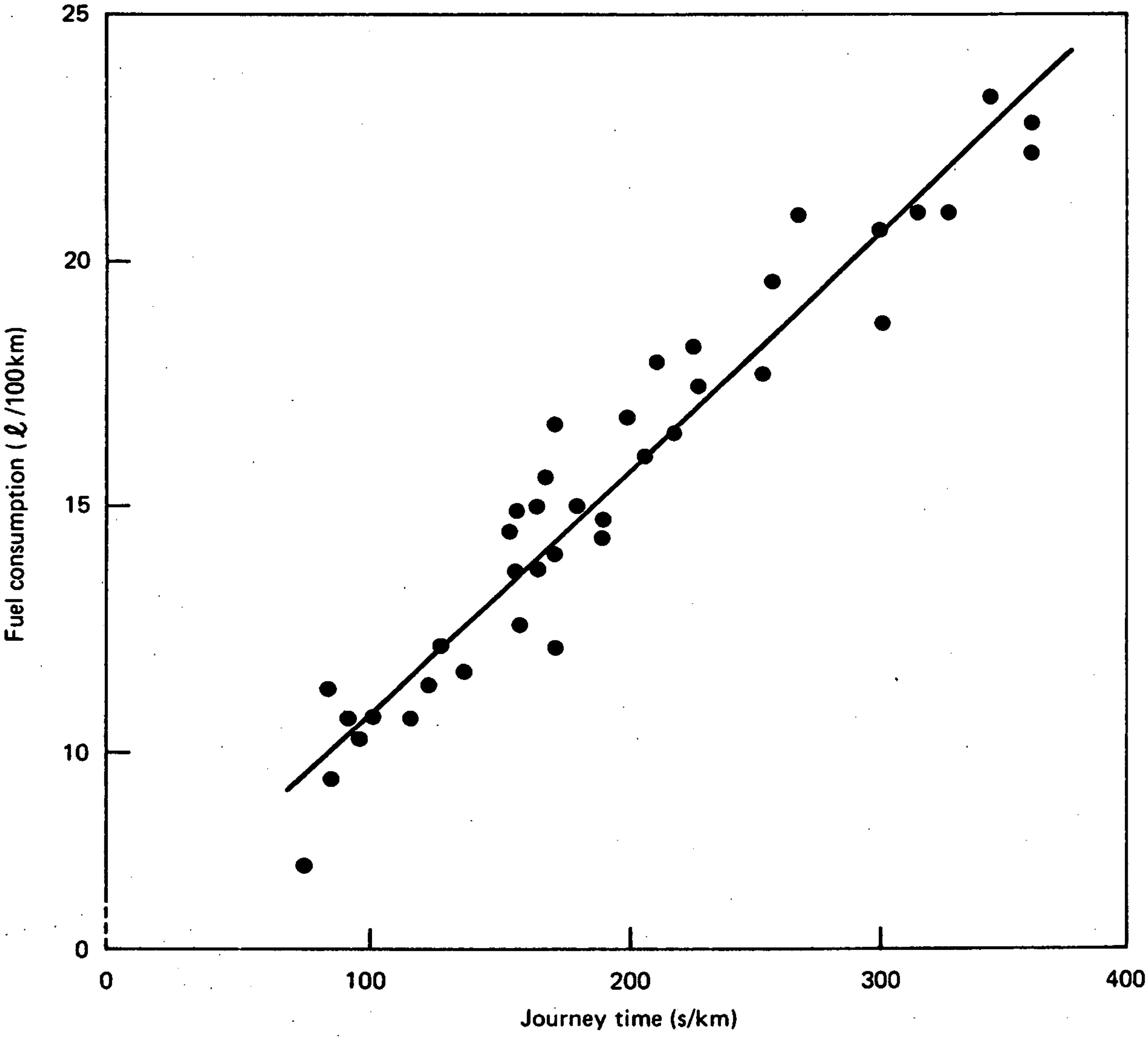

Fig. 1 FUEL CONSUMPTION OF AN AVERAGE CAR IN BUILT-UP AREAS (based on LR 226)

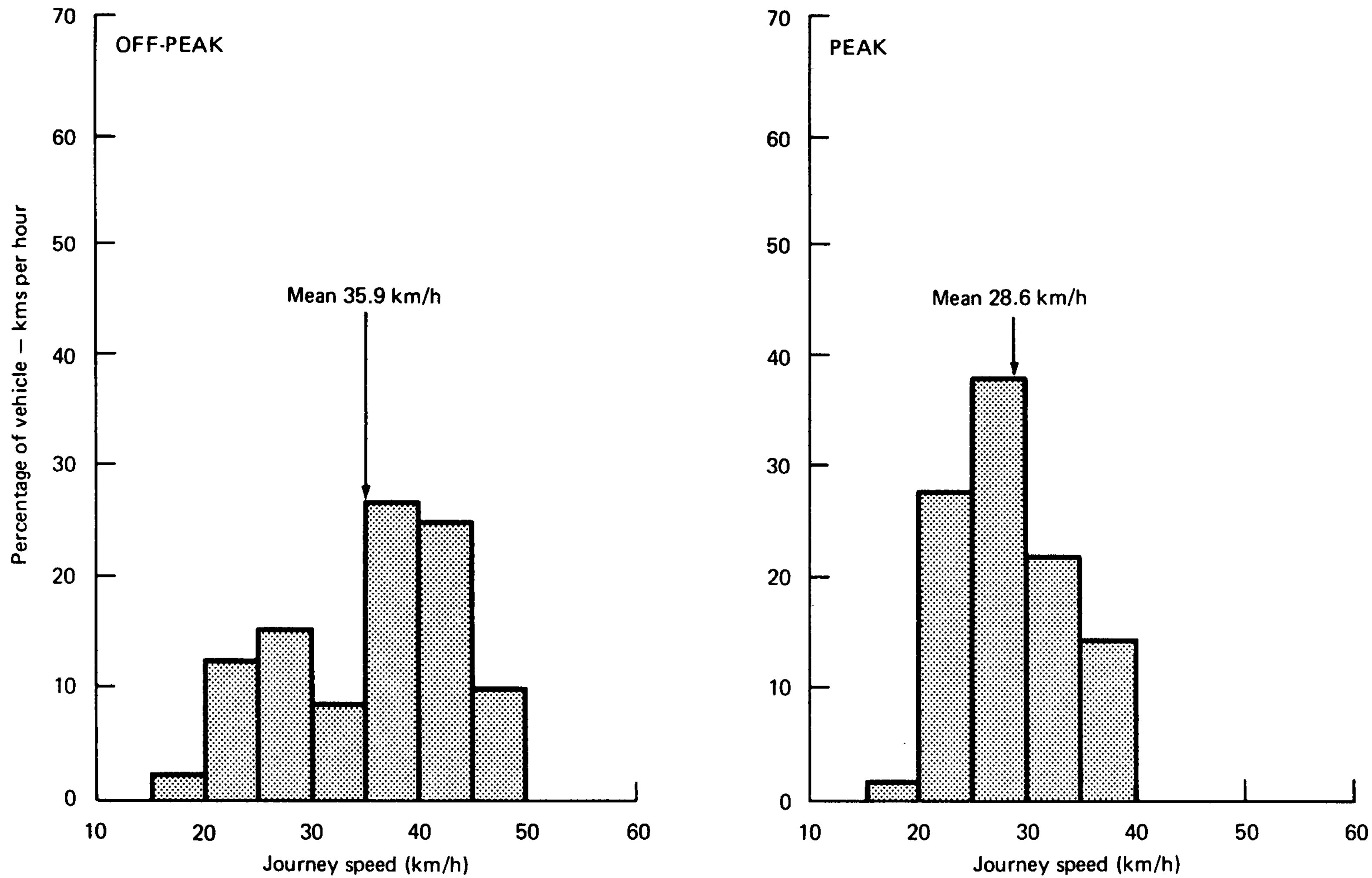

Fig. 2 TRAVEL SPEEDS : GREATER LONDON, 1976

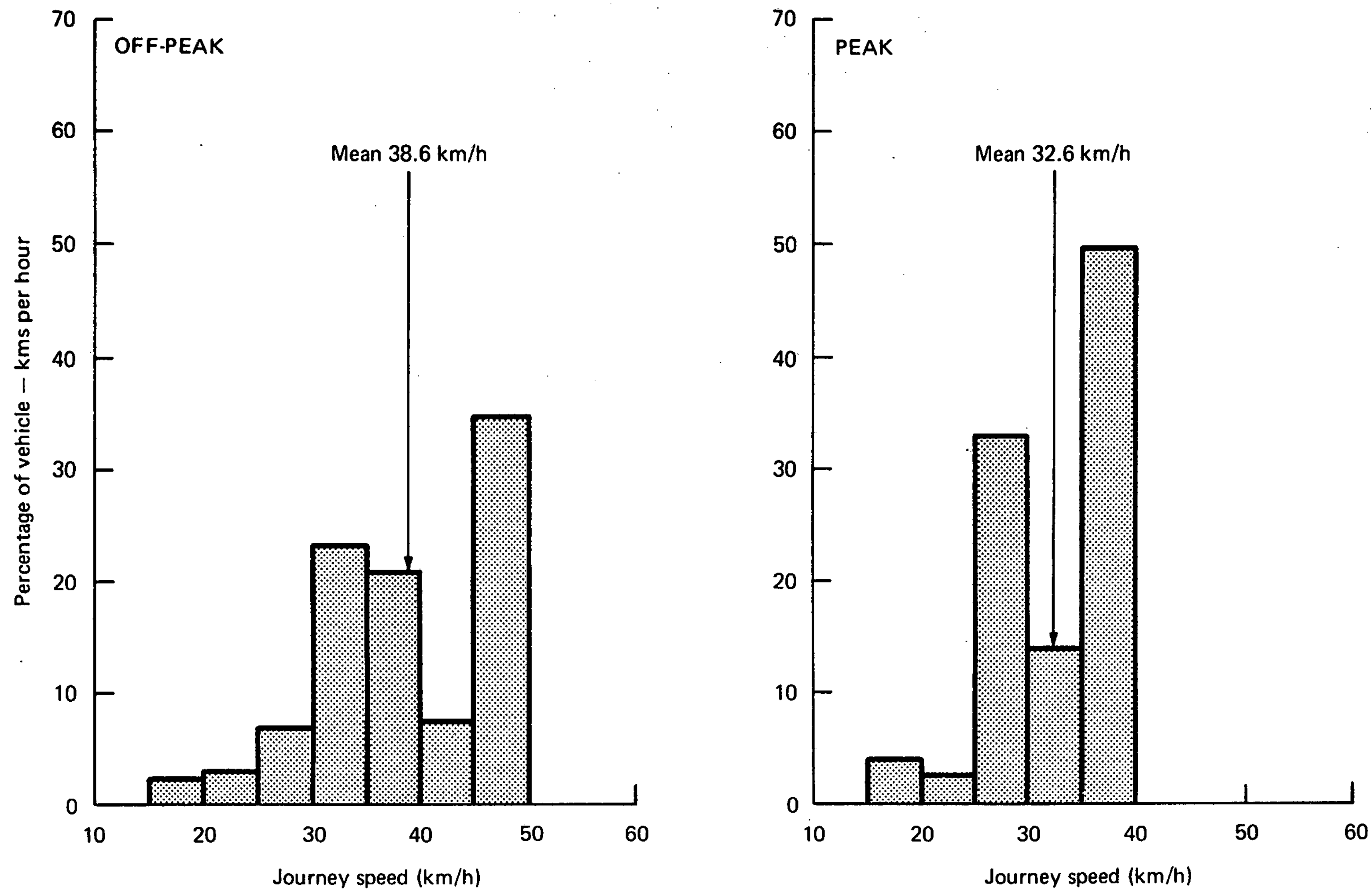

Fig. 3 TRAVEL SPEEDS : TOWNS AND CONURBATIONS, 1976

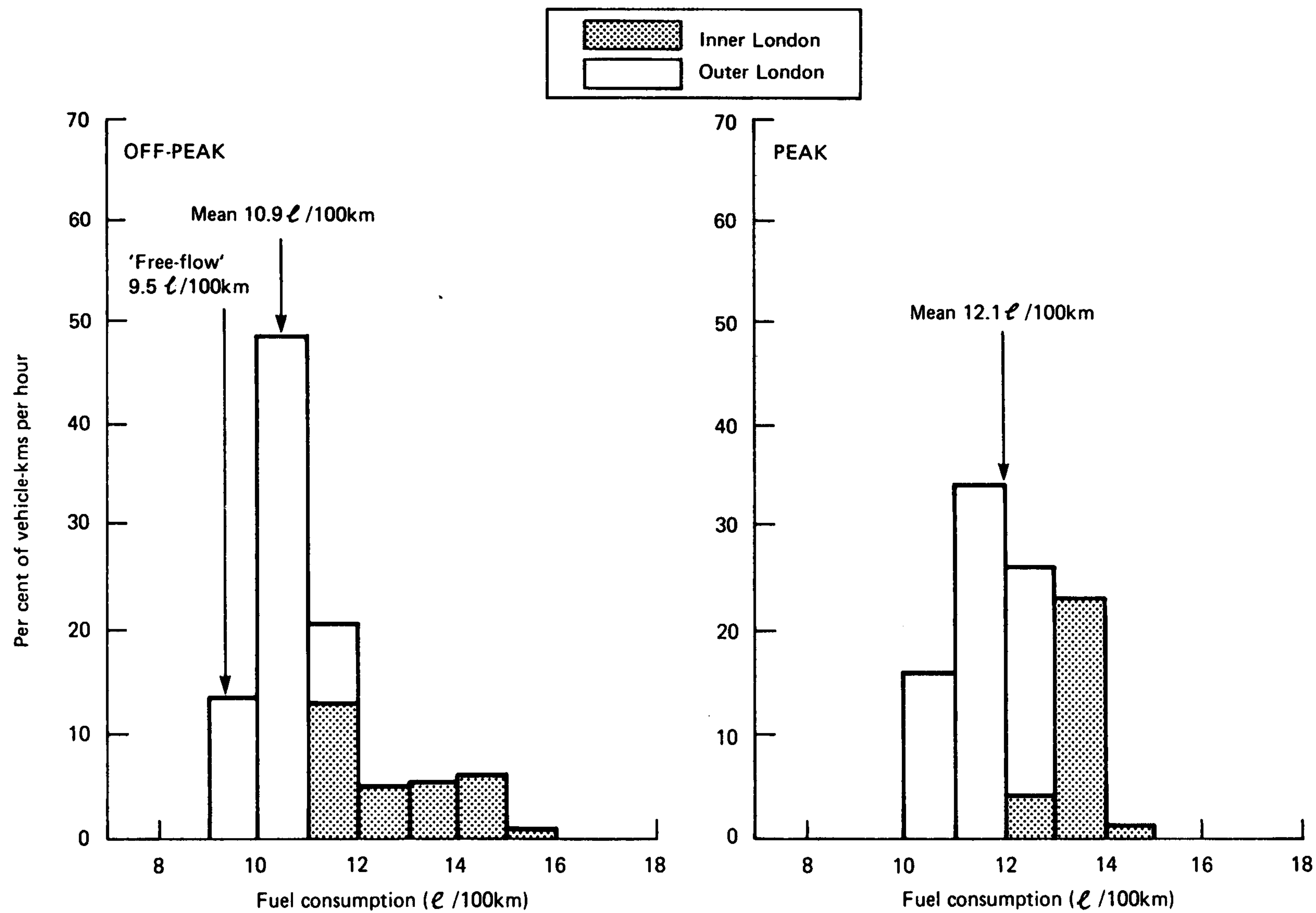

Fig.4 CAR TRAVEL AT DIFFERENT FUEL CONSUMPTION IN GREATER LONDON, 1976

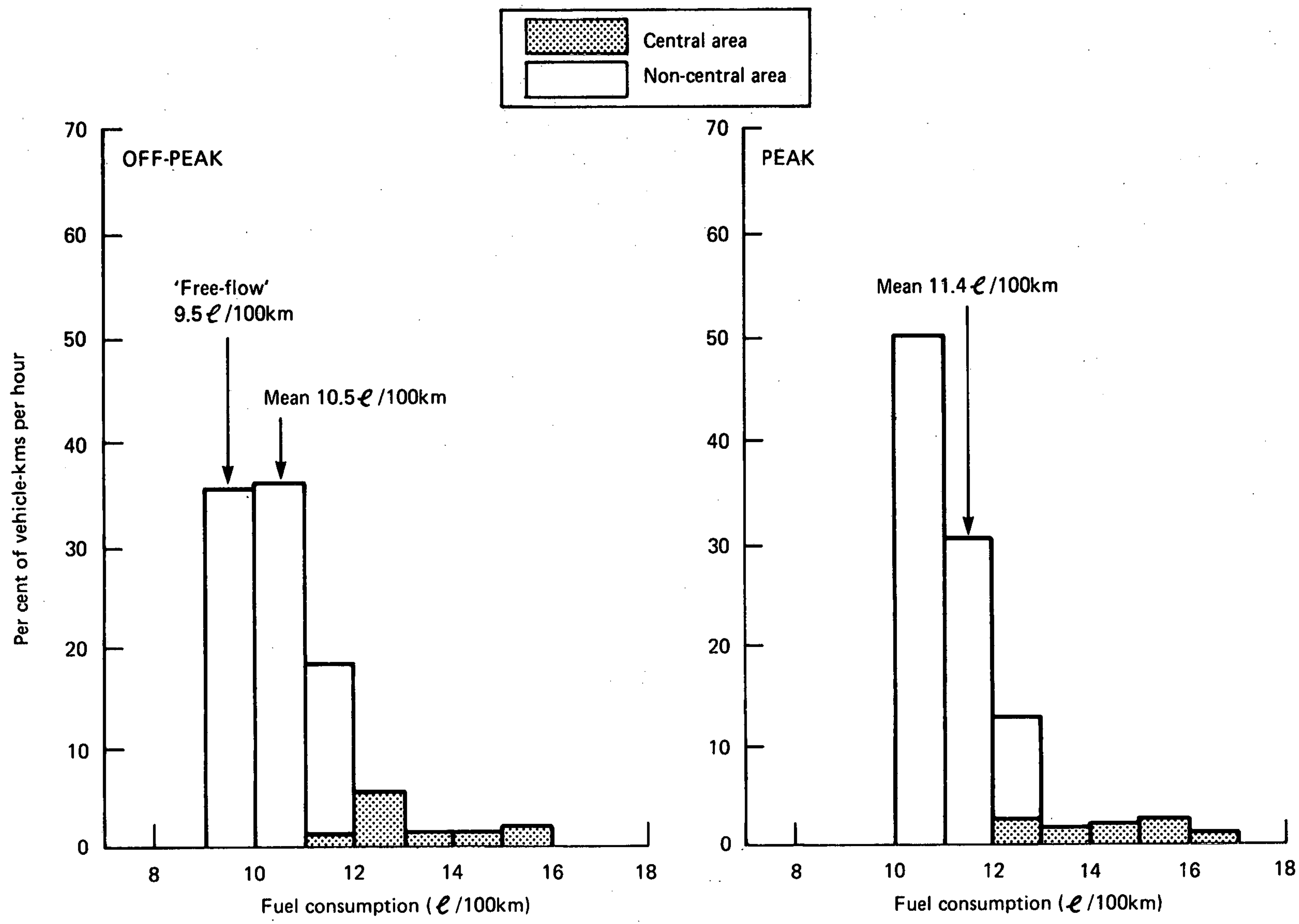

Fig.5 CAR TRAVEL AT DIFFERENT FUEL CONSUMPTION IN TOWNS AND CONURBATIONS, 1976

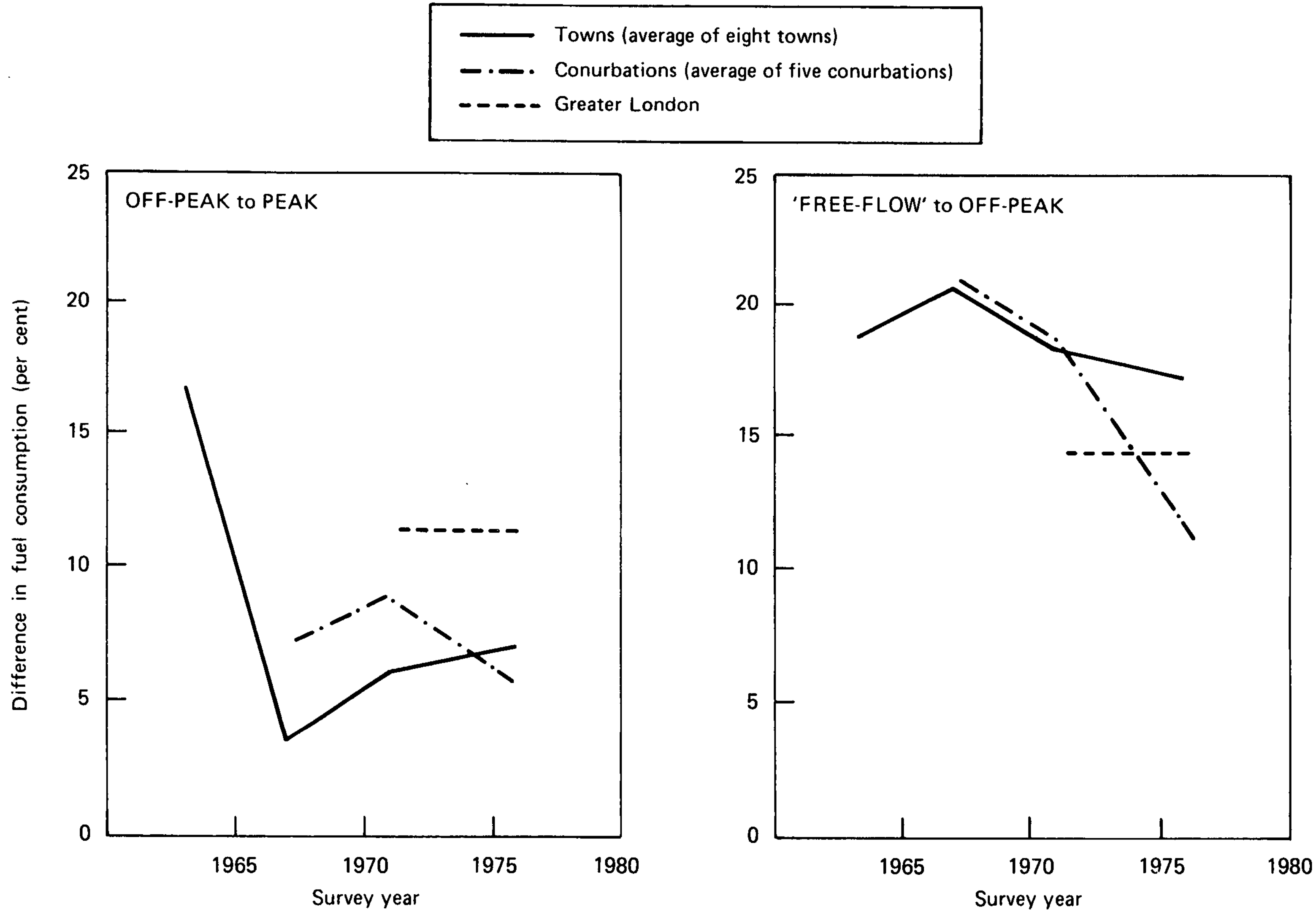

Fig.6 LONG TERM TRENDS IN THE DIFFERENCES BETWEEN OFF–PEAK TO PEAK AND 'FREE–FLOW' TO OFF–PEAK FUEL CONSUMPTION FOR CARS

11. APPENDIX

Average fuel consumption over a network of roads

The effect of traffic congestion on motor vehicle fuel consumption can be assessed on the basis of journey speed survey data and the linear relationship between fuel consumption and journey time (the inverse of average speed). Traffic surveys use different sampling procedures and present data at different levels of aggregation for analysis. In the following sections formulae are derived for calculating the average fuel consumption for the same network of roads using traffic area data or road link data or motor vehicle trip data. Furthermore, it is shown that the calculated averages, which can be used for energy saving calculations, are identical in all three cases.

11.1 *Traffic area fuel consumption*

The energy saving calculations in this report are based on the following derivations.

The average fuel consumption $\overline{f}^1$, for the whole network of roads is obtained by weighting each traffic area average fuel consumption, fi, by the proportion of travel in area i and summing the results. The proportion of total travel, $\dfrac{\ell_i q_i}{\sum_i \ell_i q_i}$, at each fuel consumption is calculated using the average total traffic flow, q_i, and the total link length ℓ_i. Thus

$$\overline{f}^1 = \frac{\sum_i f_i \ell_i q_i}{\sum_i \ell_i q_i} \qquad \text{(1a)}$$

The average fuel consumption, discussed in Section 5 of this report, is given by:–

$$f_i = a\left(\frac{1}{v_i}\right) + b \qquad \text{(1b)}$$

Where $\left(\dfrac{1}{v_i}\right)$ is the average journey time per unit distance for traffic area i,

a and b are constants.

The average journey time, average total traffic flow and total link length, used in the energy saving calculations, are known to be defined by the survey teams[14] as follows:–

$$\frac{1}{v_i} = \frac{\sum_k t_{ik} q_{ik}}{\sum_k \ell_{ik} q_{ik}} \qquad \text{(1c)}$$

$$q_i = \frac{\sum_k \ell_{ik} q_{ik}}{\sum_k \ell_{ik}} \qquad \text{(1d)}$$

$$\ell_i = \sum_k \ell_{ik} \quad \text{. . . . . (1e)}$$

Where t_{ik} is the average journey time on link k in traffic area i,

q_{ik} is the link flow,

ℓ_{ik} is the link length.

Substitution of equations (1b)–(1e) into equation (1a) yields:—

$$\bar{f}^{1} = a \frac{\sum_i \sum_k t_{ik} q_{ik}}{\sum_i \sum_k \ell_{ik} q_{ik}} + b \quad \text{. . . . . (1f)}$$

11.2 *Road link fuel consumption*

The average fuel consumption, $\bar{f}^{11}$, for the whole network of roads is obtained by weighting each link fuel consumption, f_{ik} by the proportion of travel on link k in area i and summing the results, leading to:—

$$\bar{f}^{11} = \frac{\sum_i \sum_k f_{ik} \ell_{ik} q_{ik}}{\sum_i \sum_k \ell_{ik} q_{ik}} \quad \text{. . . . . (2a)}$$

The link fuel consumption, discussed in Section 5 of this report, is given by:—

$$f_{ik} = a \left(\frac{1}{v_{ik}}\right) + b \quad \text{. . . . . (2b)}$$

Where $\left(\frac{1}{v_{ik}}\right)$ is the average journey time per unit distance on link k in traffic area i.

The average journey time per unit distance is defined as:—

$$\frac{1}{v_{ik}} = \frac{t_{ik}}{\ell_{ik}} \quad \text{. . . . . (2c)}$$

Substitution of equations (2b) and (2c) into equation (2a) yields:—

$$\bar{f}^{11} = a \frac{\sum_i \sum_k t_{ik} q_{ik}}{\sum_i \sum_k \ell_{ik} q_{ik}} + b \quad \text{. . . . . (2d)}$$

11.3 *Trip fuel consumption*

The following analysis applies to all trip survey data which can be restricted to the same network as has previously been considered. Trips which lie partly outside the network must be subdivided and the external part discarded from the data.

The average trip fuel consumption, $\bar{f}^{111}$, for the network of roads is obtained by weighting each trip fuel consumption, F_j, by the proportion of travel $\frac{L_j}{\sum_j L_j}$, of trip j and summing the results, leading to:–

$$\bar{f}^{111} = \frac{\sum_j F_j L_j}{\sum_j L_j} \qquad \text{(3a)}$$

where L_j is the trip length.

The trip fuel consumption, discussed in Section 5 of this report, is given by

$$F_j = a\left(\frac{1}{V_j}\right) + b \qquad \text{(3b)}$$

where $\left(\frac{1}{V_j}\right)$ is the average trip time per unit distance for trip j.

The average trip time per unit distance is defined as:–

$$\frac{1}{V_j} = \frac{T_j}{L_j} \qquad \text{(3c)}$$

where T_j is the trip time.

Substitution of equations (3b) and (3c) into equation (3a) yields:–

$$\bar{f}^{111} = a\,\frac{\sum_j T_j}{\sum_j L_j} + b \qquad \text{(3d)}$$

The total trip time, $\sum_j T_j$, is equal to the total link travel time, $\sum_i \sum_k t_{ik}\, q_{ik}$, also the total trip distance, $\sum_j L_j$, is equal to the total link distance, $\sum_i \sum_k \ell_{ik}\, q_{ik}$, hence substitution of total link time for total trip time and total link distance for total trip distance into equation (3d) yields:–

$$\bar{f}^{111} = a\,\frac{\sum_i \sum_k t_{ik}\, q_{ik}}{\sum_i \sum_k \ell_{ik}\, q_{ik}} + b \qquad \text{(3e)}$$

11.4 *Conclusions*

The formula for the network average fuel consumption, $\overline{f}^{1}$, derived from traffic area data is identical to the formula, $\overline{f}^{11}$, derived from link data, which in turn is identical to the formula, $\overline{f}^{111}$, derived from trip data as seen from equations (1f), (2d) and (3e). Therefore the sampling procedure and the level of aggregation used in the survey data are not expected to effect the results of energy saving calculations.

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