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AN ANALYSIS OF TRIP LENGTH AND LAND USE PATTERNS IN THE GREATER ATHENS AREA

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ABSTRACT

The research described in this paper is an attempt to quantify the impact of a certain distribution of land uses upon trip characteristics – notably trip lengths. The idea is to relate trip lengths classified by mode and purpose to the distance of one trip end from the conurbation centre. The latter is defined as the point which represents a reasonable estimate of the place where the economic, administrative, and cultural life of the urban area is centered.

By relating trip lengths to the distance of one trip end from the centre, one could obtain a relation which in effect would be a quantitative expression of the relation between transport and land use. The first application of this idea was in London using the 1966 journey to work data, and it gave quite satisfactory results.

The area examined in this research is the Greater Athens Area. The method of analysis is similar to that followed in London so the results of the two studies can be compared. Only work trips are considered for four modes: car, bus, train and all modes (total). It is found that in the case of Athens too, when distance of the workplace from the centre is considered, trip lengths change in smoothly varying ways and a series of mathematical curves can be fitted to the data with an acceptable degree of accuracy. These curves are of the Gamma family having a constant "spread" factor and varying "scale" factors for each mode considered. When the distance of the residence end of the trip from the centre is considered, the trip length distributions are not very smooth, a clear mathematical curve cannot be fitted, but again a considerable degree of order can be detected. In addition to the above results a discussion is given on their meaning and the possibilities for future research. In fact the results so far are considered to be the first stage of a more extended research programme which will eventually connect trip length distributions to income and other economic or social parameters in an urban area.

Introduction

The idea that trip length distributions can be used to demonstrate changes in land uses by considering the different patterns of these distributions by mode and by distance of one end of the trip from the conurbation centre comes basically from the work of Mogridge (1974) and Angel and Hyman (1969).

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Mogridge looked at different patterns of trip length distributions by mode, analysed according to the distance of one end of the trip from the conurbation centre. He found that in the case of London these patterns change in smoothly varying ways and that the gamma family of distributions can be applied to them as a first approximation at a strategic level. He then used these distributions to show how one can model changes in land use by predicting changes in trip lengths, using income growth as the main basis for predictions.

More recent work has stressed the importance of this field of research and has resulted in interesting findings on the interaction between land use and transport. Angel and Hyman (1976) and Orrom and Wright (1976) have used Manchester and London data to examine the spatial distribution of movement, while Blumenfield and Weiss (1974) and Blumenfield et al. (1975) have examined similar relationships, using normal distributions to relate journeys to work by mode to the spatial distributions of homes (residence end of the trip).

By relating trip lengths to the distance of one end of the trip from the conurbation centre, one connects the land use distribution, described by its direct distance from one reference point (the centre), to one of the main characteristics of the trips i.e. trip length. The main advantage in doing this is that in effect no network is used but merely continuous space over which travel is "possible" at all points and in all directions. One can thus separate the various unwanted network effects on modelling travel behaviour and examine the more important behavioural characteristics of travel over space. Furthermore, a relationship between trip lengths and land use distribution as expressed by distance (or cost or any other measure of impedence) from the centre can prove a very useful quantitative expression of the interaction of land use and transport.

The purpose of the analysis presented in this paper was to examine the applicability and to test the validity of Mogridge's approach in an area with different land-use and travel characteristics than that of London and, at the same time, to propose some improvements to the theory. Initially, the conurbation centre is defined, then data on trip lengths for each mode of travel are classified according to distance of either end of the trip from the centre. Only work trips are examined, so their two ends are the residence and the workplace. From this classification we produce the cumulative probability distribution curves of trip lengths for each end of the trip and for each mode. There are several such curves in each case, each one corresponding to distance of the trip-end being considered from the centre, classified in increments of 2 kms up to 16 kms. A mathematical curve is fitted to these data and a number of conclusions are drawn. The area examined is the Greater Athens area and the data used were collected during the Athens-Attica Transportation study (Smith et al., 1974).

Definition of the Conurbation Centre

There are several ways to define the "centre" of a conurbation. It can be the centre of gravity for the population, or for employment, or the main economic or cultural centre in the area etc. A more complex method was followed for the definition of the conurbation centre in the case of London (Mogridge and Locke, 1972), but this method [1] could not be applied in the case of Athens. The main difficulty is due to the fact that there are two major commercial, social and business centres in the Greater Athens Area: that of Athens itself and that of Piraeus. The approximate position of these two centres within the conurbation is shown in Fig. 1. If one was to calculate the centre of gravity for the total population as the conurbation centre, the result would be unrealistic in that this centre would not be anywhere near either of the actual centres. Indeed, the calculation of the centre of gravity for the total population gave a point nearly 3 kms NE of the centre of Athens; this is consistent with the pattern of urban development in Athens, which, as shown in Fig. 1, follows a SW to NE direction due to geographical constraints. Given these peculiarities of the Greater Athens

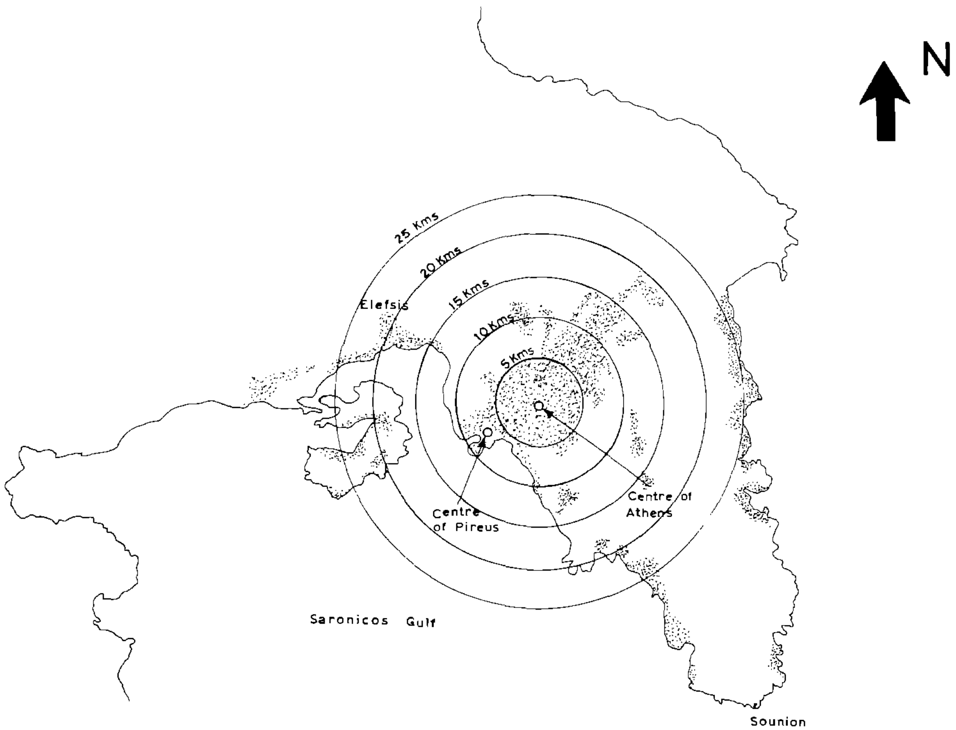

Fig. 1. Built-up area and the two major centres in the Athens-Attica region.

area, it was decided to adopt the main commercial, business and administration centre of Athens as the conurbation centre. The place selected was Syntagma (Constitution) Square which lies roughly at the point shown in Fig. 1. The influence of the second major centre in the area (Piraeus) is accounted for by a corrective technique used during the data analysis and described below.

Derivation of Data and Method of Analysis

Trip lengths were derived by a series of traffic assignments using 1972 origin-destination survey data (Smith, 1974) and the roadway and public transport networks, the description of which included the time to travel along each link under prevailing (1972) conditions. Only work trips were considered.

The whole of the Greater Athens area, which covers approximately 3,200 sq. kms, was divided into 264 traffic zones. These zones constituted the basic unit for the origin or destination of trips, which were considered to start and end at the zone centroid. Trip lengths were calculated in minutes because in this way the traffic conditions prevailing in the network and influencing travel behaviour are implicitly taken into account. The classification of the trip lengths according to the distance of one end of the trip from the centre, was made by a specially written computer program which included an algorithm for the manipulation of the data so as to take account of the second major centre in the area. This was done as follows. Out of the 264 traffic zones, 14 were identified as having a direct activity relationship with the centre of Piraeus. Trips to and from these zones with a length less than 15 minutes were classified as having "distance from the centre" equal to the distance of these zones from the centre of Piraeus rather than the conurbation centre. The idea behind this treatment was that within the total area of the conurbation, the centre of Piraeus acts as a (local) point of attraction which influences travel behaviour in the same way as the conurbation centre. For trips with a length greater than 15 minutes, it was assumed that their behaviour was conditioned by the conurbation centre and therefore these trips were classified in the same way as all other trips. The validity of these assumptions was tested and the 15-minute limit was determined following a series of computer runs with and without the adjustment for Piraeus and with different values of the "limit" trip length. The results of these runs were examined as to their internal consistency and from this examination the adequacy of the 15-minute trip length was established. The tests were made for "car" and "total" trips only.

Trip Length Distributions

The trip length distributions of four categories of trips, according to the mode of travel, were calculated. The four categories were: private car, bus, rail (i.e. the one existing line connecting Piraeus with Kifissia, the northern suburb of Athens), and trips by all modes ("total"); walking was not considered. For each of these categories, a family of curves was derived for

TABLE I

Trip Length Distribution of (Work) Car Trips by Distance of Workplace from the Conurbation Centre

Distance of Workplace from centre (kms)	Percentage of trips with length less than (mins)					
	5	10	15	20	25	30
0– 2	6.04	15.50	29.18	58.20	66.02	67.13
2– 4	8.15	20.42	36.12	60.29	68.13	70.18
4– 6	19.01	39.09	62.22	71.08	74.84	74.07
6– 8	16.25	36.18	59.31	67.38	72.31	72.09
8–10	21.36	45.82	73.32	82.91	84.68	85.18
10–12	28.38	50.91	76.01	85.66	88.67	90.34
12–14	25.71	54.73	78.09	87.52	89.08	90.62
14–16	30.01	56.18	83.00	89.71	92.12	94.02

TABLE II

Trip Length Distribution of Bus Trips by Distance of Residence from the Conurbation Centre

Distance of residence from centre (kms)	Percentage of trips with length less than (mins)							
	5	10	15	20	25	30	35	40
0– 2	37.15	66.60	85.21	95.80	96.18	98.01	98.90	99.20
2– 4	25.44	62.33	75.32	88.41	93.10	94.30	96.15	97.31
4– 6	19.52	49.76	65.28	74.35	76.35	78.12	79.07	82.28
6– 8	13.63	37.62	48.71	58.07	61.52	65.14	68.88	71.07
8–10	12.08	32.51	46.07	55.14	55.80	57.08	58.70	62.32
10–12	10.04	30.32	41.38	49.07	52.68	53.44	55.18	58.55
12–14	9.80	27.07	37.66	45.02	46.15	48.54	50.22	52.61
14–16	8.15	23.19	36.52	39.30	40.12	43.62	45.31	46.07

various distances of each end of the trip from the conurbation centre. Two examples of the kind of data derived from this process are shown for car and bus trips in Tables I and II. The complete set of curves is shown in Fig. 2–9 [2].

Following the example of the London analysis, a gamma distribution was fitted to these data. The form of the gamma distribution is (following the notation used in Mogridge, 1974):

$$P(x) = \lambda^{\alpha} \cdot \chi^{\alpha-1} e^{-\lambda\chi} / \Gamma(\alpha)$$

Where, $P(x)$ is the probability density function,

χ is the trip length,
λ is the scale factor and
α is the spread factor,

$\Gamma(\alpha) = \int_0^{\infty} e^{-x} x^{(\alpha-1)} dx$ is the Gamma function.

The mean trip length (μ) is related to the spread and scale factors with the formula $\mu = \alpha/\lambda$. It is also a function of distance from the centre. For each family of gamma curves there is a fixed value of the spread factor and a number of values for the scale factor. The results of the analysis for each mode of transport are briefly discussed below.

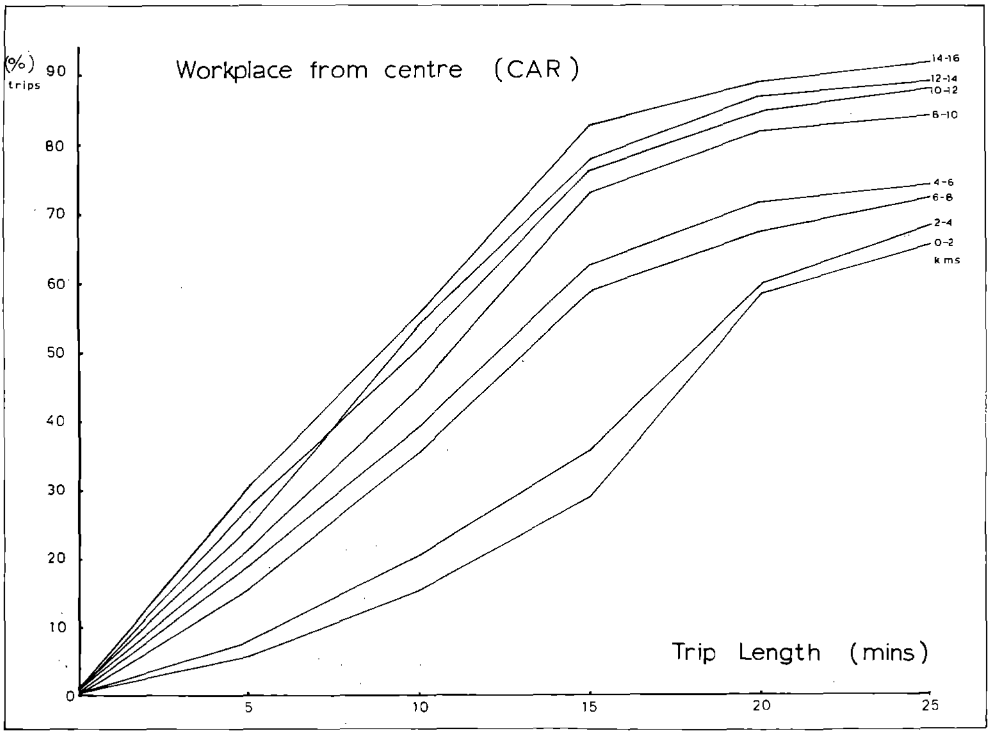

Fig. 2. Trip length distributions for car trips by distance of workplace from the centre.

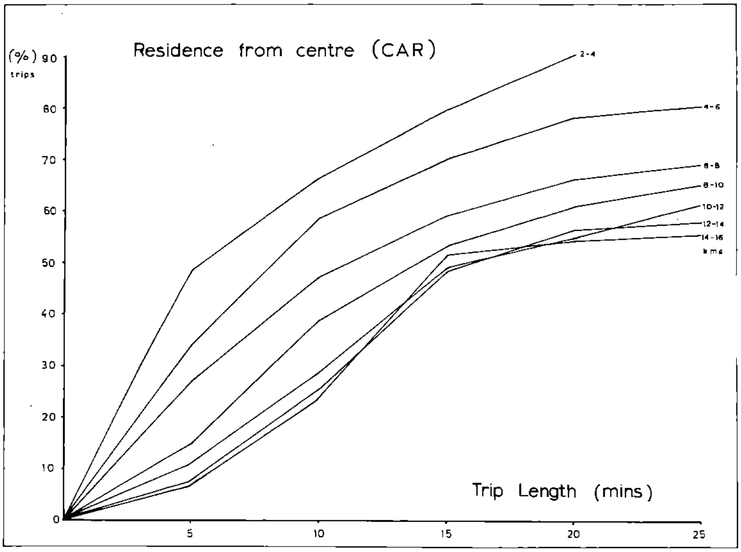

Fig. 3. Trip length distributions for car trips by distance of residence from the centre.

CAR TRIPS

When the distance of the workplace from the centre is considered, the spread factor of the gamma distribution which best fits the data was found to be α = 3.3. The mean trip length varied from approximately 15.6 mins in the 0–2 kms range from the centre, through 13.5 mins for 2–4 kms, to 10.1 mins at the outermost ring, but at the 8–10 and 10–12 kms rings the mean trip length was approximately 15 minutes. This irregularity may be explained by the existence of the second centre in the area. For the distance of residence from the centre a more complex pattern exists, especially in the 10–14 kms range as can be seen in Fig. 3. For these distributions it was not possible to calculate a gamma function.

BUS TRIPS

For buses the average trip lengths are greater than those for cars but follow a similar pattern of change.

For the distance of workplace from the centre, the curves shown in Fig. 4, can be approximated by a gamma distribution with a spread factor α = 2.9. The mean trip length for 0–2 kms from the centre was approximately 31.0 mins, for the 2–4 kms ring 28.3 mins, and it was lowest at the 14–16 kms ring where it was 19.8 mins.

For the distance of residence from the centre, again, a more irregular pattern appeared (Fig. 5). Trip lengths are shortest in the centre with a mean value of 9.5 mins and increase progressively, with radius, to 29 mins. As shown in Fig. 5, the shape of the distribution changes as we move progressively from the centre to the outermost rings. This creates difficulties since it is not possible to calculate a single family of gamma distributions which fits this category of data. A negative exponential distribution might give a better approximation.

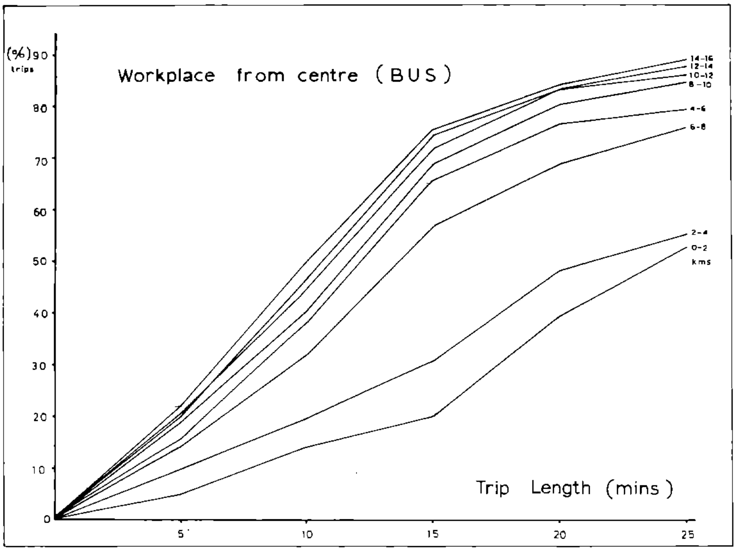

Fig. 4. Trip length distributions for bus trips by distance of workplace from the centre.

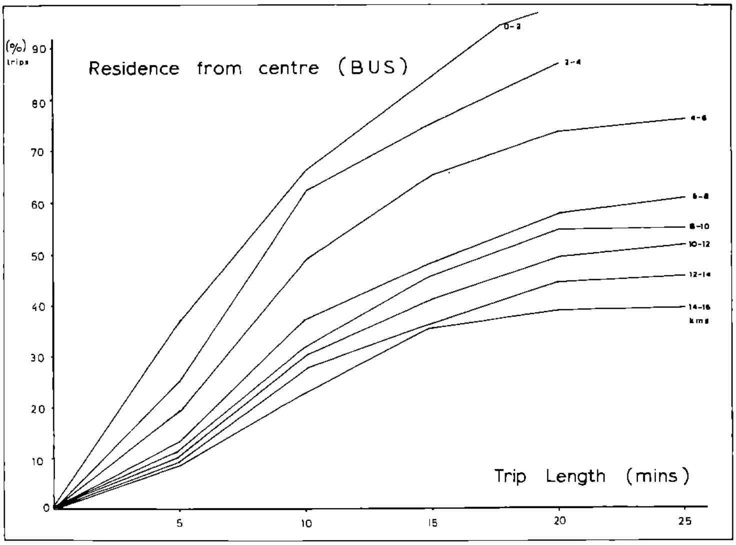

Fig. 5. Trip length distributions for bus trips by distance of residence from the centre.

RAIL TRIPS

For the distance of workplace from the centre (Fig. 6), the trip lengths are smoothly distributed and they were fitted with a gamma distribution of $\alpha = 2.4$. The mean trip length of all data is 15.6 mins while mean trip lengths vary from 13.5 mins in the 0–2 kms area to approximately 22 mins in the outermost ring.

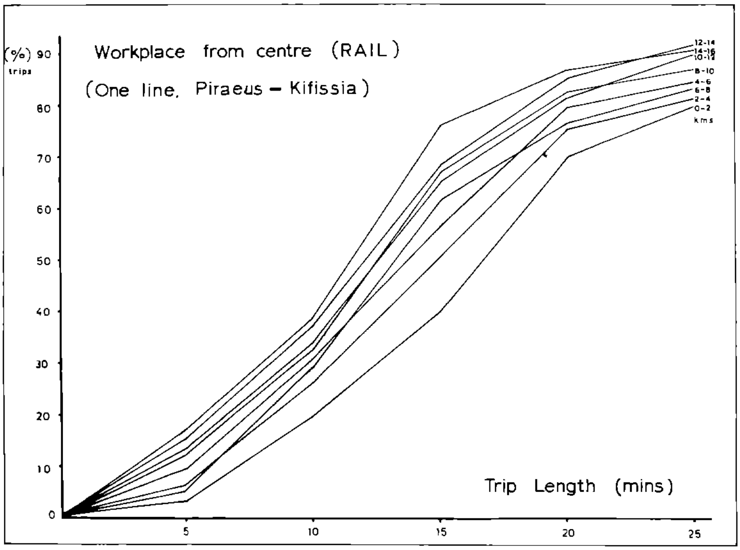

Fig. 6. Trip length distributions for rail trips by distance of workplace from the centre.

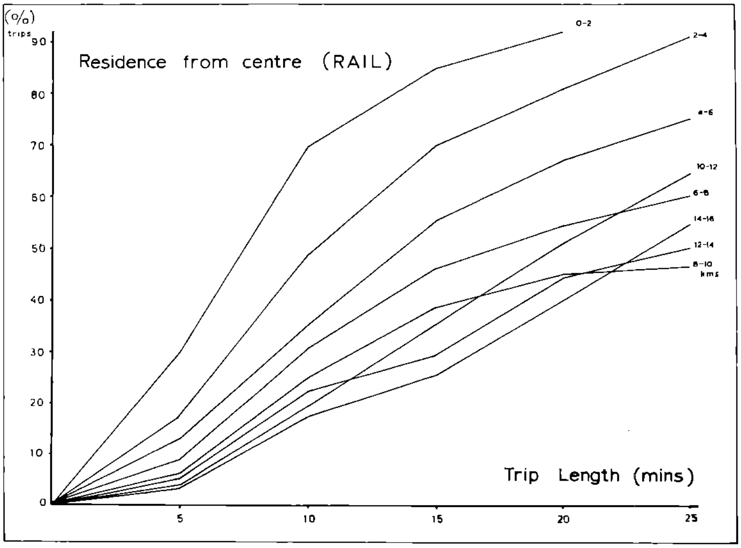

Fig. 7. Trip length distributions for rail trips by distance of residence from the centre.

For the distance of residence from the centre, the curves show a rather mixed pattern which does not fit either the gamma or the negative exponential distribution (Fig. 7). This may have its explanation in the fact that rail trips in the Greater Athens Area are served by the only existing line from Piraeus to the centre of Athens and then to its Northern suburb, Kifissia. It would appear that the distribution of households which use this one line may be considerably more extended and complicated than the one which might normally be expected to exist if a more extensive network of railway lines was in operation.

TOTAL TRIPS

Finally, the distributions of all trips, irrespective of the transport mode used, were calculated by distance of both the workplace and residence from the centre; these distributions are shown in Figs. 8 and 9. Again, the curves for distances of the residence from the centre are not easily fitted with a mathematical curve. For distances greater than 4 kms they are quite irregular. Disregarding these irregularities, especially at the 4–6 and 12–14 kms rings (Fig. 9), an effort was made to fit a mathematical curve to these distributions as well as to the ones referring to distance of workplace from the centre (Fig. 8). The best approximation was a gamma distribution of $\alpha = 3.2$ for the workplaces and 4.6 for residences. The data in Figs. 8 and 9 show a distinct separation between the curves up to and beyond 4 kms from the centre, especially when distance of the residence end is considered (Fig. 9).

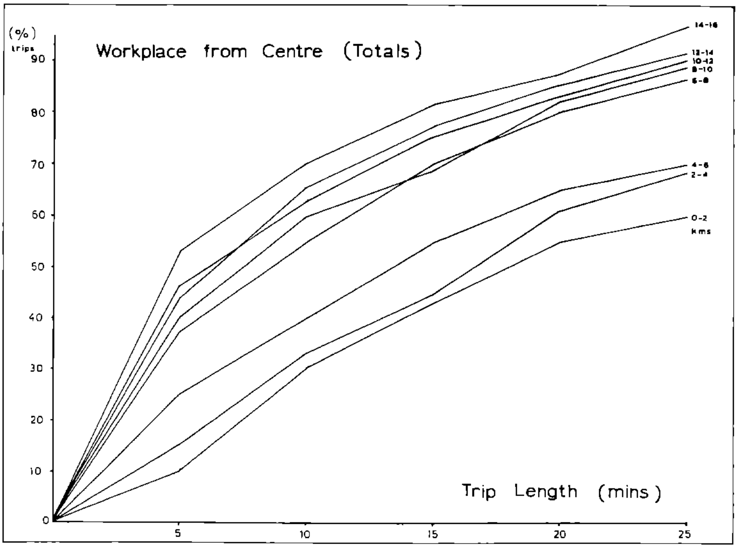

Fig. 8. Trip length distributions for "total" trips by distance of workplace from the centre.

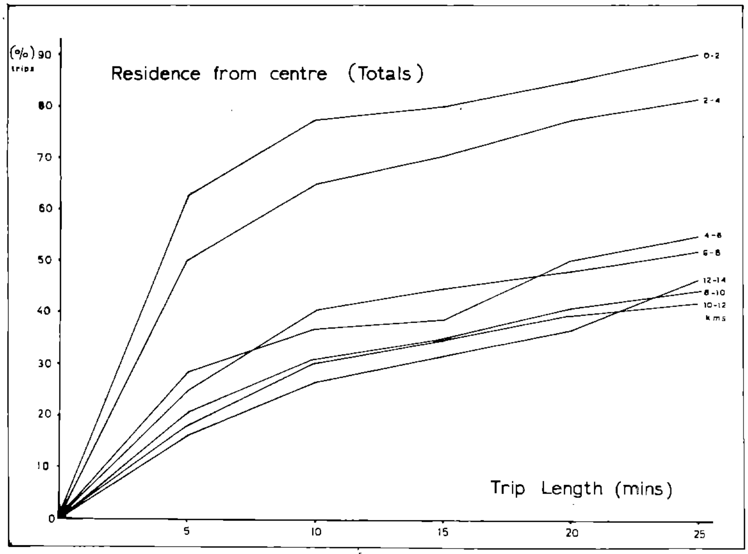

Fig. 9. Trip length distributions for "total" trips by distance of residence from the centre.

This means that trip lengths suddenly increase quite disproportionately at that point. Similar irregularities are also noticed in the curves for the other modes, but to a lesser degree. The distance of approximately 3–4 kms round the centre(s) where this happens may well signify a zone of congestion, where most of the traffic starts to be channeled towards its final point of destination. In any case, I am sure this is an important point to be examined further, and it may prove an objective criterion for the definition of the central, congested, area of a city.

Changes of Mean Trip Length According to Distance from the Centre

A more concise picture of the changes in trip lengths is obtained by plotting the mean trip lengths for a given distance from the centre. In the following, we give one example of these curves, for total trips (Fig. 10) which represents a good indication of trip making habits in the area. The mean trip length in the Greater Athens area for all modes considered is 23.5 mins when the distance of the workplace from the centre is between 0 and 2 kms. This length decreases rapidly to approximately 6.5 minutes when the work end of the trip is within 6 and 8 kms from the centre and remains almost the same thereafter [3]. The curve in Fig. 10 also represents the change of the λ values which correspond to each of the curves in Fig. 8. The spread factor of the gamma distribution fitted to the family of curves in

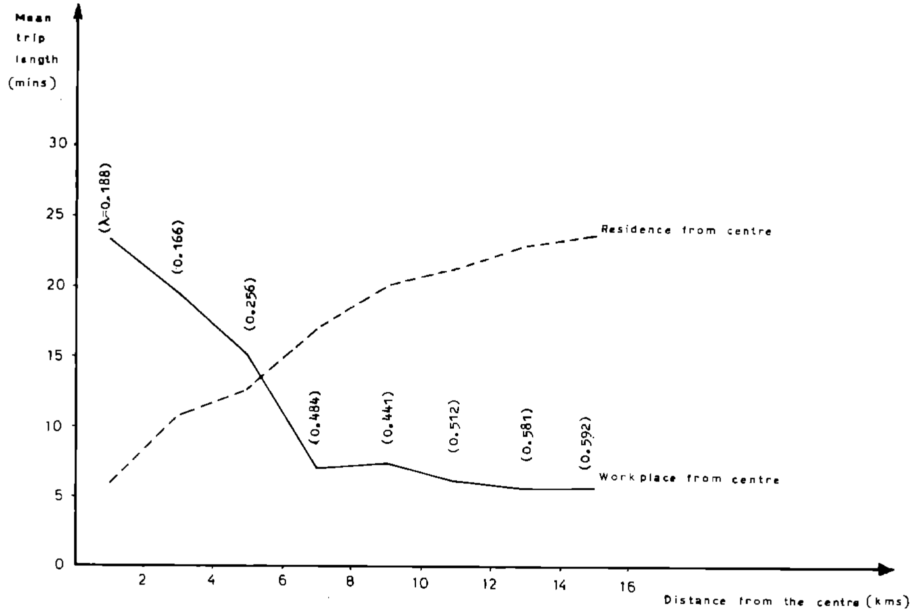

Fig. 10. Distribution of mean trip lengths for all modes ("Total" trips).

Fig. 10, is constant and is connected with the scale factor λ and the mean trip length μ by the formula $\mu = \frac{\alpha}{\lambda}$. Thus for each μ plotted in Fig. 10 there is a corresponding λ value; these are given in Fig. 10 in parentheses.

When we plot the mean trip lengths by the distance of the residence end of the trip from the centre, the opposite trend is noticed. If the residence is at a distance of between 0 and 2 kms from the centre, the mean trip length is approximately 6 minutes. This increases progressively to 13.5 mins at 4 to 6 kms and to almost 25 mins at 14 to 16 kms from the centre. It is worth noting that the curve for residence shows a continuous growth. This is probably an indication that in the Greater Athens area the location of a household is not primarily conditioned by the location of the workplace and the trip length involved, but by other factors, most probably the level of rents.

Conclusions

Perhaps the most significant finding of the analysis so far is that trip lengths in the Greater Athens area can be related to the distribution of workplaces by a series of mathematical curves of the gamma family which have been defined as a result of the analysis. This means that, by using a constant spread factor and a varying scale factor, one can reproduce the varying pattern of trip-making in the area using as a parameter the distance of the workplace from the centre. For example, for trips to work by all modes, the proportions $P(x)$ of trips having trip length less than x minutes, is given by:

$$P(x) = \lambda^{3.2} . x^{2.2} . e^{-\lambda x} \; / \; {}_{o}\int^{\infty} e^{-x} \, x^{2.2} \, dx$$

where λ varies according to the distance of the workplace from the centre as shown in Fig. 10. Representative values of λ can be obtained from the analysis of the data so far.

The spread factors for the trip length distributions are not directly comparable in the cases of Athens and London because in the latter they were not calibrated but were derived from direct graphical inspection. These factors as they stand today appear to be greater in the case of Athens. If this continues to hold true after the calibration of the London values, it will mean that for the same λ values the Athens data show greater variance i.e. there is a greater dispersal of trip lengths (this is because $\sigma^2 = \alpha/\lambda^2$).

Although trip lengths in minutes show a greater variability, they also provide a better representation of reality especially when one considers public transport trips. Taking into account our results so far, their use instead of distance is therefore justified.

When distance of residences from the centre is considered, the distributions are more difficult to fit with a mathematical curve but a good approximation is again the gamma distribution and, in some cases, the negative exponential. In this respect, we experience in the case of Athens the same difficulties as Mogridge did for London. The forces that influence the distribution of residences are complex and this is reflected in the trip length curves for residences. In theory, residential income and expenditure for travel to work should be implicitly expressed in trip length distribution curves similar to those for workplaces. One of the reasons for the distortion is probably the conditions in the market in rent but it is unlikely that these conditions alone will explain the situation. The next stage in this research will be an effort to connect the trip length distributions by distance from the centre to distributions of income at the residence or the workplace end of the trip, taking into account trip costs by mode. This stage will also include the calculation of the effect that orbital movements have on the form of the trip length distributions. Such movements are far less important in the Greater Athens area than they are in London, due to the topography and the radial road network that resulted from it. However, in the future, the number of such trips will increase as more peripherals are going to be built, and thus a methodology is needed for the determination of their effects on the form of the trip length distributions by distance from the centre.

As was also mentioned in the introduction of this paper, the practical results of the research when completed will be that the interaction between land use and transport will have been quantitatively modelled in a way that can be used both for the description of an existing situation as well as for predictions.

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Notes

1 According to this method the centre of gravity for the total population is first found and then the cumulative population distribution formed, based on increments of population contained within circles round that centre with increasing radius at 1/2 km intervals. Assuming a negative exponential fall in population density with respect to distance from the centre, a gamma distribution of second order gives the population living in the ring at a given radius. An estimate is then made of the radius within which the existing population data gives the best fit to this gamma distribution and this radius is taken as the cut off point in the data analysis. The final centre of the conurbation is the centre of gravity for the sub-set of population data contained only within the circle of that radius.

2 Trip lengths were calculated up to 40 minutes for bus and 30 minutes for the other modes; in the figures, however, they are plotted only up to 25 mins.

3 The data available for "total" trips, include walking and other categories of trips. Thus, the average figures for "total" trip length may not correspond to what would he obtained if one considered the total of car, bus and train trips which were examined separately in this paper.