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Two Scenarios for Traffic Restraint: the Traffic, Social, and Environmental Effects.

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ABSTRACT

Different measures have been proposed to restraint the traffic in towns to give pleasant environmental conditions, and to allow traffic to move at a reasonable rate. These measures include parking controls, road pricing, supplementary licences, physical barriers, and cordons of toll points round congested areas. The theoretical techniques required to analyse these policy proposals in a transport planning context have now been developed together with environmental impact appraisal methods, and a full study of the effects and the limitations of these different forms of traffic restraint has been carried out on two scenarios based on those designed by the City of Coventry for their Transportation Study. The situation in 1967, when a low level of parking control was quite sufficient to meet the practical and economic objectives, has been studied to show how the different restraint policies might be best analysed in lightly congested conditions. The 1981 forecast situation under the low investment option considered in the Coventry Study was then modelled to determine the effects and the economic results of different restraint schemes under the difficult conditions expected for that year. Traffic benefits are not the only positive results of restraint, and a special environmental impact assessment model has been developed and applied to show how the noise, smoke, lead, carbon monoxide, nitrogen oxides, and airborne hydrocarbon concentrations would affect people under each restraint option. It is clear that although the design of restraint systems can reasonably be undertaken, and the traffic and high levels of environmental impacts forecast, the evaluation of environmental factors to similar standards cannot at present be achieved. The distributional impacts, which could have wider social consequences, are also presented to show how different restraint instruments can have divergent distributional results even when the overall benefits reach the same aggregate totals. The scenarios used were not specifically tailored to the actual condition, present or expected, in the City of Coventry, and would have required considerable variations to achieve this. Comparative runs with other such scenarios did not, however, substantially alter the nature of the relative results discussed.

1. INTRODUCTION

Traffic congestion and the noise and air pollution caused by traffic are all increasing. Many of the journeys made would not be undertaken

if travellers bore a greater part of all the costs imposed on others by their trips, and it is possible to obtain better use of the transport system in a city or town by taking measures to bring travel demand and total social costs into closer agreement. Research and development at TRRL has produced several sets of equipment suitable for pricing the use made of roads by a system of automatic toll collection.(Smith OECD) Other methods have been pr posed, such as a supplementary licence for travel in the centre of cities, or systematic parking controls on a large scale. These measures to restrain traffic are directed more towards a better use of the restricted travel capacity of our existing city centres than to improving the local environment for residents and pedestrians, although any measure affecting traffic will in turn influence the environment of householders, residents and pedestrians. The design and assessment of a traffic restraint scheme is the subject of this paper, and the likely impacts of different schemes are calculated and compared on traffic, geographical, social and environmental grounds.

Methods developed at TRRL for the analysis of traffic restraint alternatives were developed(1) using a model designed to represent an average city, which was therefore idealised in a number of important ways. The demands on internal consistency and flow assignment stability that proved to be necessary for this strategic study had not previously been tested in a specific transportation study. This report describes the application of the TRRL equilibrium models of traffic flow, and the TRRL models on environmental impact, to traffic restraint within two scenarios based on Coventry, and gives a broad picture of the range of traffic Cnd environmental changes that might arise from a range of practical restraint policies.

Two very different study years were considered for Coventry - 1967, and a special version of the position forecast for 1981 conditions. In each case the evening peak hour was studied, as in Coventry this is the period of greatest sustained congestion. The conditions in 1967 were not excessively congested, and the delays suffered by travellers were comparatively light. However, the forecast 1981 situation was substantially congested with considerable overloading on some roads.

The situation forecast(2) by the Coventry Transport Study

Group (CTSG) was forecast on the basis that no anticongestion measures would be taken in the first instance. The CTSG then constructed a balanced forecast by matching parking provision against the excessive demand for travel.

In order to construct a more extreme situation the basic level of congestion was raised even beyond the CTSG forecasts by reducing the road space outside the City boundary as represented in the model, and leaving the level of travel demand unadjusted at the previously forecast level.

The same process was carried out for the 1967 model, but due to the low level of travel demand outside the city in that year this had little effect on the overall level of congestion.

We were therefore provided with two extreme scenarios which enabled us to draw broader conclusions from the results than would have been possible using a pair of less extreme situations. One objective of this work was to investigate the effects of traffic restraint within clearly defined areas, providing a cross section of typical conditions of a general city. These have been termed Local Analysis Areas (Figure 1a), and practical survey work[3] on these local areas provided the basis for the work on environmental impacts caused (or decreased) in these areas by traffic restraint.

The 1967 scenario was used initially to test out in a practical case the application of the methods developed using an idealised city[1]. The level of congestion in Coventry at 1967 was such that lessons learnt from the idealised city could be used as an effective guide to the effects of restraints in Coventry in the 1967 scenario adopted.

Many of the objectives and models used in our previous studies of traffic [1,4,7] restraint were appropriate to this project. A range of fixed restraint policies with different charges and applied over different regions of the city were compared with each other, and against both a theoretical optimum scheme and nonfixed restraint methods.

The results of the Coventry (1967) model were also compared with those of the idealised city and when possible the two sets of results related. It would be dangerous to draw too many direct comparisons between the results of the Coventry (1967) and idealised

and idealised city network models, as several major differences exist between them, both in the data used for the models and the assumptions made in the modelling.

However, the results for the two networks taken both individually and together provide a broad view of a wide range of problems associated with restraint in general.

The restraint model used for Coventry treated goods and passenger service vehicles separately from private vehicles, and bus passengers from other travellers, unlike the models on the idealised city which aggregated all vehicles and travellers into one composite group. This earlier work used data applicable to 1968 conditions whilst all Coventry data refers to 1967 as the base year. The benefits from traffic restraint were not expected to be large in 1967, but for future years (exemplified by 1981) the benefits were expected to rise rapidly as the level of congestion increased to a substantial level. The zoning structure adopted was derived from that used by the Coventry Team [2]. The zone boundaries inside the city boundaries are shown in Fig 1b.

The flow assignments obtained for the 1967 scenario were checked both for internal stability and for agreement with the screen line counts taken in Coventry in 1967. The use of the same speed and flow relationships for the TRRL model adopted by the Coventry Transportation Study made comparisons possible between 1967 ground counts and the TRRL 1967 model predictions, but the operation of the model showed that the use of speed flow relationships on a link by link basis could cause problems in establishing an internally stable assignment, making it difficult to detect the equilibrium when reached.

The 1967 study showed us the peculiarities and idiosyncrasies that arose when applying the TRRL transportation models to Coventry. We were then able to model the 1981 situation with the greater degree of confidence in spite of the heavy congestion in our version of the unrestrained 1981 scenario. The 1981 base position was compared with that of 1967, but it was difficult to do this in any great detail in view of the extreme nature of the two situations.

For restraint modelling in 1981 the matrices of goods and private vehicle movements were treated as a single combined demand for travel, but there was a separate matrix for travel by bus. Four basic fiscal restraint schemes were considered but a wide selection of mixed policies and special policies were also investigaged. Full discussion of the models and their results are given in section 3, where a comparison is drawn between the TRRL model predictions and those of SIA

Ltd. The consequences of each restraint measure were studied in terms of total traffi effects and environmental (noise and air pollution) impacts on the resident population

Special attention was paid to the variations in travel demand and trip length over Coventry, particularly in and around the railway triangle (Figures 1c, 1d), where most of the restraint policies took greatest effect.

These results are presented mainly in the form of contour diagrams in Section 4. The variations in total generalised trip cost over the city due to the application of traffic restraint are also shown in diagrammatic form.

This report describes two complete limiting scenarios on the effects restraint in Coventry in uncongested (1967) and extremely congested (1981, enhanced congestion) cases. The range of analyses described in this paper show how far transportation models may be used to assess traffic restraint policies and also some broad indications can be drawn as to how best to restrain traffic in Coventry in the future.

2. THE 1967 COVENTRY SCENARIO

The models used to evaluate restraint policies are designed to find a unique equilibrium of link flows and costs over the networks under a variety of conditions. The assignment and re-routing of trips over the networks require some mechanism for route choice and it is assumed here that the travellers act to minimise their perceived sum of vehicle operating, time, and direct money costs, on a link by link basis. The sum of such link costs over the minimum cost path between two zones in the network defines the total inter-zonal costs. Changes in these inter-zonal costs determine the change in the number of people wishing to travel between the two zones.

The idealised city [1] is reasonably representative of an urban area the size of Coventry and can broadly be compared with the central areas of Leeds or Sheffield. It covers an area of about 30 square miles and is composed of about 400 one way links and 41 zones in 5 ring roads and 10 radial arms. Each link of the synthesised network was assigned an appropriate speed-flow relationship derived from area journey-time data collected in a number of different cities.

A trip matrix was synthesised from a combination of relationships between trip demand with journey distance, and population density with distance from the centre, for a constant number of trips/person. It contains an evening peak-hour effect, where more trips leave the centre of the network than enter it.

The perceived behavioural cost function for all consumers, and applied to all links on the network was:

Link cost per km = $0.803 + 10.83/v + 0.000028\ v^2 + 60.83/v$ + link toll pence
(This represents weighted average pcu operating and time costs in 1968)

The network representing Coventry in 1967 is shown in Figure (2). This area covers approximately 35 square miles. The network includes 1200 one-way links and 83 zones. Unlike the idealised network, each link was given a speed-flow relationship dependent on its physical type and geographical position. Consequently journey-time data was not used. This led to some convergence problems when running the models and it might be more satisfactory and realistic to use area journey-time data in future, or a mid-link nodal network system for more detailed work.

The zoning system shown in Figure 16 is closely related to that used for the Coventry TSG. The external zone boundaries follow the administrative boundary of the City in 1967. A total of 73 zones were used within this boundary. These were mainly subdivisions of zones used in Coventry's travel surveys from 1961 onwards. Each zone contains about 2000 households. In addition to the 73 internal zones, 10 external zones were used to represent trips from and to the sub-region around the city boundary. These 10 zones cover the compass sectors - (ie N, NE, E etc) - and impose a weighted average cost penalty on all trips joining and leaving the city network with one end in an external zone. The trip totals for these zones were produced by combining groups of sub-regional zones used by the Coventry Transportation Group.[2]

A trip matrix of total passenger car unit (pcu) movements over the network in an evening peak hour, synthesised using data from household interviews in Warwickshire, was provided by the city of Coventry. This matrix is not identical to the one used for the CTSG environmental evaluation which was constructed from household interviews, taken only in Coventry. A commercial vehicles matrix for the same periods also exists but is of poor precision. For this report a goods matrix was synthesised by simply taking a constant percentage of every pcu movement to be 'goods' such that the correct total numbers of commercial vehicle trips over the whole network as observed in 1967.[2]

The cost function describing the behaviour of all travellers on every road link was derived from TRRL 1967 data[7] and weighted by the observed traffic composition in Coventry in that year.[2]

The data for the generalised cost function used in the RRLTAP models was derived from reference 11. Road users behave as if they perceived their net operating costs. For the following vehicle categories these were:-

Cars	$1.54 + 73.4/V + 0.00005V^2$ p/km
Light Vans	$2.06 + 104.3/V + 0.000015\ V^2$ p/km

Othergoods	$4.77 + 123.6/V + 0.00032\ V^2$ p/km
PSV (Public Service Vehicles)	$5.41 + 625/V + 0.000026\ V^2$ p/km

Taking Coventry's 1967 traffic composition from observed [2] screen-line counts:

Private vehicles: 82%, Goods 15% of which 55% are light, and PSV 3%.

Using these proportions in the operating costs, we have:

Cars	$1.27 + 60.6/V + 0.00010V^2$ p/km
Light vans	$0.17 + 7.8/V + 0.00001V^2$ p/km
Other goods	$0.31 + 8.1/V + 0.000001V^2$ p/km
PSV	$0.15 + 17.8/V + 0.000001V^2$ p/km
	$1.91 + 94.9/V + 0.00014V^2$ p/km

The PSV component includes the bus travellers value of time and double counting if the bus benefits are added directly to the model's estimates. The results are presented in this paper do not contain double counting and are 'composite vehicle' values with forced transfer figures also given (but not included in the total benefit figures) for sensitivity analysis.

The use of these values for time and distance costs is not entirely compatible with the equity time valuation recommended for evaluation in a National context. The substantial difference between the generalised cost functions adopted and the relevant "equity" values could cause severe distortions in a behavioural model of this kind: an appreciation of these effects can be obtained from the results of cost function variation reported in Reference 13. Units of d/mile are those quoted in Reference 11, but in p/km terms the cost function for travel on each link.

The demand for travel between each pair of zones was calculated at every modelling stage from the observed matrix of trips and the current total costs of movement between each zone of the unrestrained network flow mode. Some of the groups of vehicles and people were allowed to alter their travel behaviour with changes in travel cost. This "elastic" travel behaviour means that a change in interzonal costs was reflected by a change in their demand for that journey. For the idealised network, the elasticity of demand was set to unity for all vehicle categories, so that a 1% rise in journey or inter-zonal cost produced a 1% reduction in trip demand. The effects of alternative assumptions for trip demand elasticity and overall congestion levels have been discussed in an earlier

report [4] which refers to marginal social cost pricing schemes and the results can be summarised as:

1) The benefits to be derived from pricing are sensitive to pcu demand elasticity (E) only for values of up to about 1.5.
2) There is a very rapid rise in benefits as the general level of congestion rises.

For Coventry (1967), a distinction was drawn between private vehicles and goods traffic. Goods vehicle traffic was assumed to be inelastic in trip demand and therefore continued to make the same number of journeys under any restraint scheme and only private vehicles reacted to the changes in journey costs. The private vehicle demand was set to unity, in agreement with a recent review of travel elasticity, and this effectively gave an overall trip demand elasticity of about 0.75 which may be compared to unity for the idealised network.

2.1 Equilibrium assignment of traffic flow to the unrestrained 1967 Coventry network

The assignment of the total pcu matrices for both idealised and 1967 Coventry networks used the perturbation model described [7] elsewhere. The precise technique used for the idealised network[3] differed slightly from the very similar method employed for Coventry (1967) where the assignment could be checked against observed screen-line counts taken in 1967.[2] The matrix used had not been previously calibrated against these screenline counts and some fairly large discrepancies were found. Overall the total cross-cordon pcu flows predicted by the assignment model were 13% higher than those found in practice.[8]

Part of this discrepancy is due to the degree of re-routing produced by the perturbation models in their search for the stable and unique equilibrium. The final equilibrium state reached by these models represents a somewhat idealised condition in which all vehicles are using their optimum paths. Although commuter traffic may eventually attain this state in practice, vehicles on other journey purposes are more likely to use only main roads. Consequently the TRRL models predict a greater spread of the trips over the network than is likely to occur in practice. The effect of this is to increase the apparent traffic on the network, as many of the optimum routes are longer than some of those actually used. Although it could be argued that the assignments do not therefore represent the actual siguation, there is no other equilibrium state which could be used that provides a consistent framework for economic assessments. The remainder of the discrepancy is explained by the reduction in road capacity outside the city boundary in the

in the TRRL (1967) model, which forced more traffic than would actually go through Coventry to use roads within the city.

The assignment for the CTS environmental evaluation using the Coventry resident's matrix also showed significant differences between predicted and observed screen count totals, and a comparison of the final cross-cordon flows predicted by each model as a percentage of the observed totals is shown in Figure (3a). Each of these assignments used a different trip matrix but it is noticeable that the largest errors in both models occurred on the same screen-line-EE. This screen-line crosses the A45 - (Birmingham to M1), and it would thus appear that both matrices considerably over-estimate the number of through trips across the network. Overall the CTS assignment shows marginally better agreement with the observed flows but this can be attributed to the improved quality of their matrix used which has been calibrated against the screen-counts, and to the greater detail retained in the network outside the city for the Coventry assignments.

A detailed comparison of the CTS and TRRL link flows shows reasonably good agreement with the observed flows but this can be attributed to the improved quality of their matrix used which has been calibrated against the screen-counts, and to the greater detail retained in the network outside the city for the Coventry assignments.

A detailed comparison of the CTS and TRRL link flows shows reasonably good agreement in the centre of the network allowing for the effect of the different zonal connectors used in each network - (the CTS network had 115 city zones instead of 73). Less satisfactory agreement was found towards the outer areas of the city as in these areas the link connectors to and from the sub-region on the sparse TRRL network are not joined to the equivalent nodes used by the CTSG network. This factor alone accounts for most of the major discrepancies in the flow. In particular TRRL flows in the South West extremities, are much higher than the CTS values. This in turn affects the relative levels of traffic found in the neighbouring South and West regions. The same type of switching effect can be seen in the North and East with TRRL flows lower in the North but higher in the East.

The remaining discrepancies which exist between the two assignments can reasonably be explained by the goods movement pattern used in the TRRL total trip matrix. This was synthesised from the private vehicles matrix by simply multiplying every element derived from the observed proportion of goods vehicles crossing the screen lines. However there are more external private vehicle trips to or from the city than the overall proportion of goods thus giving the TRRL matrix a higher level of incoming and outgoing flow across the external boundary than in the flow assignments adopted by the CTSG.

On almost half the main ring and radial routes, the overall agreement between the flows was within 10%, although individual links showed some discrepancies. The agreement was significantly better towards the centre of the network on those routes with differences of between ± (15 to 19)% compared with ± (23 to 25)% in the outer regions.

The Coventry Traffic and Transportation Plan for 1970[8] includes some data on observed flows for that year, and where possible these have been compared for the two assignments. There is fairly good agreement between the observed flows and those from the TRRL assignment, most roads being within 10% and none worse than 30%. The CTS assignment gave differences of up to 50%. Although it would be dangerous to assume too much from this comparison, it would seem that the TRRL assignment is a reasonable simulation of the actual network in 1967 and is not inconsistent with the final assignments accepted from the CTS model.

The restraint models used on both networks have also been described previously.[1,4-7] The TRRL models for Coventry (1967) were a little more sophisticated than those for the idealised network as a distinction was drawn between private vehicles and goods traffic, and each group was considered separately. The goods flows were assumed to remain unaltered by any fiscal changes, but not network ones. Their link flows were taken into account when determining link speeds and hence time and operating costs, but otherwise the models concentrated on the private vehicles. The final benefit evaluations include the consumers gain of both private and commercial vehicles - the latter group being an amount equal to their tolls paid but gaining some of this back through their faster journey times and cheaper operating costs due to the private vehicles priced off the network. Results for the alternative viewpoint that goods vehicles are not priced - are also given.

Our previous work on idealised networks[4-7] stressed the practical importance of finding a unique and stable assignment equilibrium before the succeeding economic and network evaluations were undertaken. The equilibria reached by the models can be tested in two different ways: (1) link costs can be forced into agreement with the associated link flows as implied by the relevant speed-flow relationships, and a comparison drawn between prior and resulting networks. To make this comparison, we calculate the benefit/loss total accruing to the consumers for each network compared with some other known network state. Ideally the change in consumer surplus value should be small or zero, and proved to be an effective check on convergence for both idealised and Coventry networks, (2) removal of the toll or other changes on the network to determine whether the system will return precisely to its pre-restraint state with further assignment and demand modelling (under the same conditions previousl

used to reach the solution now used as a start point). If the system does not return to the original state, the former base equilibrium has been proved to be unstable. If the original base situation had not been checked, any forecast for a particular restraint scheme based on it would derive an apparent extra benefit owing to the more efficient assignment of the traffic achieved en route to the forecast. This improvement is not due to the restraint scheme but could have occurred even if no restraint had been applied due to the additional stages added to the model. This test is simply an extension of the perturbation model's equilibrium search process. The pre-restraint assignments are normally subjected to a sequence of different perturbations of this kind until the system returns to its previous unperturbed state when the lastest perturbation has been removed.

During the initial stages of this restraint modelling programme it was also necessary to treat each of the restraint policies under study to ensure that all such potential systematic errors had been removed. This could be checked by confirming that each such amount of a policy in reverse did indeed reproduce the same unrestrained equilibrium situation.

The testing framework used for previous work[1,4-7] was a simulation of the evening peak in a circular town of 41 zones and 390 links. Tests on this network showed that the removal of the tolls returned the system to almost exactly the same state. It was proved harder to reach this level of stability on the Coventry network in a reasonable amount of computer time. This was partly due to insufficient perturbations being made in the pre-restraint modelling and partly due to speed-flow relationships based on link type, width, and geographical position. Some of these relationships used by the Coventry Study Group had extremely steep slopes and were thus very sensitive to small changes in flow. The idealised network's relationships were based on overall journey-time information and the slopes took various values of up to 10 times less steep than the most severe relationships used for Coventry. As link speed-flow relationships take little account of junction or turning effects there seems little point in using these on networks containing a dense concentration of intersections.

Tests were set up to use a "multi-routing" technique whereby the travellers between each zone pair randomly over and under-estimated their link perceived costs to improve the convergence of the 1967 Coventry models. It was found that the improvement in convergence was negligible for random misperceptions of up to 20% in total perceived generalised costs on each link. But for values higher than this, the convergence rate was actually reduced. The cause of this effect is that large misperceptions may disturb the system so much that they never allow the model to approach the unique equilibrium and in such cases produce a less efficient assignment

than with smaller or no cost misperception.

The extent of any deficiency in the convergence of the Coventry models was determined by backtracking - removing the restraint tolls - from the forecasts resulting from four different policies and comparing the final state with the former pre-restraint situation. Although none of these four runs returned to the former pre-restraint state, they all converged within acceptable limits to the same new position. It was found on average that the results predicted had over-estimated the benefit to private vehicles by just over 350 pounds per hour, to goods vehicle by about 250 pounds per hour and to bus travellers by around 200 pounds per hour. All the backtrack runs lay within 6½% of these values, and these factors were subtracted from the benefit figures obtained by the models. It would appear that apart from the other factors adversely affecting convergence already described, insufficient perturbations were carried out initially when determining the prerestraint equilibrium. However the general robustness and overall consistency of the results is not in question since each of these backtrack models returned to precisely the same state whatever policy or level of charges was considered.

It is interesting to compare the final link flows predicted by the backtrack models with the observed screen line counts to see whether any improvement has been achieved in the agreement of measurement with assignment. Figure (3b) gives the new ratios of assigned to observed flows for the backtracked results and our former assignment. These ratios allow for an overall 2% excess loading added to the network due to the accumulative effect of minor rounding errors in the model. A slight improvement in this new assignment was obtained. It should however be noted that the matrix of trips used for this assignment had not been calibrated against the observed screen line counts by the CTSG, as the goods and P.S.V. flows were included only in an approximate way. Neither of these factors helped the assignment but the final errors are similar to those accepted for the joint DoE and CTSG environmental evaluation.(2)

The technical details of this congested assignment are worth discussion, as a number of practical points may be made. The perturbation model used to obtain convergent assignments operates by imposing an elasticity of demand for travel on the network and simultaneously applying a notional charging or road alteration policy to the network. The model mechanism that reacts to these conditions is then used a number of times before the notional policy is removed and the mechanism works to try to "restore" the network to the original undisturbed state. If it is successful, convergence has clearly been achieved, if it is not, then the system has moved down to convergence. A basic part of this technique is a sequence of iterative loadings at each stage. Experience with a range of networks has shown that a sequence of 20%, 15%, 10% iterative loadings is generally suitable until the final stages, when 15,

10, 5 may sometimes yield an improvement. The usual ill effects of iterative loading are removed by selective unloading (or loading) on each route in the network. The size of each element in the matrix (M) of loading (+ve) and unloading (-ve) trips is determined by comparing the current number of trips and the current trip cost with the number of trips forecast for this cost by a simple demand model (as used only for this perturbation process). If M is multiplied by a factor before use, values of less than unity clamp the correction process, while values of greater than unity amplify it. Values of below 0.6 slowed down convergence, and values of 0.6-1.0 are normally used. The cost of a congested assignment model of this kind can be high, especially if great precision is essential. While such precision is necessary for a study of this kind, there are many cases when the extra cost will be difficult to justify. The additional benefit, of establishing the unique solsution or that the system is close to it, might on some occasions justify the use of a single perturbation stage in a conventional model, but the comprehensive use of convergence improvement processes is likely to be necessary only when large (or small) scale traffic management measures are under study. When several stages of perturbation are involved, it is necessary to vary the type and magnitude of the notional proposal used at each successive perturbation. It is also necessary to realise that very small perturbations can be counter productive in that they cause insufficient disturbance of the system to allow any assignment improvement to take place. The use of 'Burrell' (or rather 'von Falkenhausen') multirouting devices can slow down convergence unless only a trivial degree of random "misperception" is allowed. Experiments on this Coventry network demonstrated that over 20% variation in the link "length" in this process showed convergence markedly. Before 20% there was some suggestion of a minor improvement in convergence rate, but this was hardly significant.

The actual behaviour of the 1967 scenario convergence produced by perturbation models is shown in Figures 4 and 5. Figure 4 shows how each perturbation stage proceeds. Convergence is confirmed by the third perturbation, when an improved estimate of goods movement demands was introduced ("Trip matrix Adjusted"), and it is clear that the final convergence was achieved in a single stage, although it took one further perturbation to confirm this. Figure 5 shows only the upper and lower bounds on the establishment of convergence which are provided by the points linked by dotted lines to the continuous curve of Figure 4. This convergence process was carried out with no prior knowledge of the network and demand characteristics and shows a welcome degree of robustness to the details of the precise perturbation procedure used.

2.2 Representation of restraint policies in TRRL models

Many of the medium and long term solutions proposed to alleviate traffic congestion involve fiscal changes or network capacity changes. Current examples of such restraints are parking meters, London's ringway system and the closure of

streets to traffic. In this report we consider several possible methods for fiscal restraint and the effects altering network capacity, and some of these and their variations are shown in Figures 6 and 7.

The most extensive fiscal restraint policy is that of marginal social cost charging ("road pricing") where users of each road pay precisely the cost that their presence imposes on other users. Such a scheme would be impossible to implement in its pure form as road users would be unable to react to such a finely graduated and ever changing pattern. However, if applied universally, the scheme gives the maximum benefit that can be derived from fiscal restraint and as such provides a benchmark against which other practical policies over less extensive areas may be judged. Charges for using a given road are a function of the flow on that road (and on certain network parameters as defined in reference 4), and equate the marginal social and private costs for travel on each road.

The five practical policies considered were supplementary licences (Fig 6c), parking charges (Fig 6a), pricing point system (Figs 6d, 7a, 7c), a cordon of charges (Figs 6b, 7b) and a physical restriction (Fig 7d) on access to the railway triangle. A supplementary licence scheme imposes a flat rate charge on all trips within a specified area as all such trips, whether leaving, arriving, or passing through this area are forced to pay an extra charge on top of their normal journey costs. The restraint model represents this scheme by imposing a cordon of charges of a fixed size around the specified area applied to all traffic passing into and out of the area and by applying another set of charges within the area of equal size to all zonal links connecting the zones to the network. Each trip, into, through, or out of the region then pays a total toll of 2t.

There are some problems in interpreting this model of supplementary licencing. In practise it is likely that a supplementary licence would be required for movement within a specified area for a set time period. The view implied in our modelling representation is that we are concerned only with effects on specific journeys from one zone to another within that time period. For the full complexity of a supplementar licence scheme to be picked, the model would have to take due account of <u>all</u> journeys made by each individual in the time period for which the licence applies, and also the likelihood that he would time his journeys to avoid requiring a licence at all In purely practical terms this is not a practical modelling proposition as data would be required not only for trip origins and destinations, but also on whether a journey was the first or a subsequent trip in the restraint area and the means by which the road users' decision to make subsequent trips would be influenced by the fact that they have already paid for a licence. The test assumption that can be made is that most of the traffic in the peak hour consists of commuters, and that these commuters make only

a pair of one-way trips in the two peak periods, ie to and from work. The charge set in the model then represents half the daily charges or the average charge for the one-way journey. The model charge is in fact the optimum charge for the one-way journey and has only an indirect relationship with the optimum daily charge through further hypotheses of this kind since the licence rate depends on the average number of trips made by each vehicle in a day. Consequently our model does not adequately represent a daily licence system for those trips which make more than one two-way journey in the restraint area nor those which make only a single one-way journey. The approximate representation of such trips will influence the values of benefits derived but it is difficult to determine by how much or indeed in which direction this influence will act. There are further subtleties involved when scaling the benefits up from the hourly totals predicted by the models to the daily and annual quantities required for assessment. The charges, set in the model simulate the level required in each (peak) hour of the day to restrain the traffic to its predicted level. Consequently the forecast benefits must be scaled up by the number of (peak-equivalent) hours in the working day. If however this charge were to be applied for only one period in the day - am peak for example - some of the traffic then restrained would have been present in the next period - pm peak - , but is not now there to be charged since these travellers have either found alternative modes or ceased to travel. It might then seem that - at least for commuter traffic - it is only necessary to charge one of the peak periods, or alternatively that the daily charge should be only half the peak hour charge, which would then contradict our previous interpretation. This second interpretation is fallacious. Even if we applied a supplementary licence to only one of the peak periods on the assumption that the other peak time would be affected to the same degree, we would then ignore all trip generation effects and all trips which now alter in times of their previous journey to benefit from the reduced congestion in the unsurcharged peak period. A more substantial reason for rejecting these arguments is that the models are basing the travellers trip decisions on the journey costs experienced in one peak-hour. Commuters making one trip in each peak period base their trip decisions on the costs they will experience before returning to their origin - ie on the round trip - and thus may be taken to split the cost of the licence equally between the costs of each of the one-way trips. The hourly benefit simulated by the model should therefore be scaled up to a daily total by factoring up by the number of peak-equivalent-hours in a day.

The parking tax system is rather different in intent to present day meter schemes. All trips terminating in the restraint area would pay a flat rate charge which could be graded by district if need be. Representation within the model is not as straightforward as might be thought since a parking tax would only be applied at the destination of each journey.

In the model of the evening peak hour such taxes would appear to be ineffective as the critical direction of movement is out and away from the congested restraint area. As for a supplementary licence, we are concerned not with the actual journey cost but the average costs of a journey or half of a round trip cost. Consider a traveller who goes from zone A to zone B and then on to zone C before returning to zone A. His total trip cost from A to B is the cost of travelling from A to B plus any parking taxes he incurs at zone B; his total trip cost from B to C is the cost of travelling from B to C plus any parking taxes he incurs at zone C, and his total cost from C to is the cost of travelling from C to A plus any taxes he incurs at zone A. However his decision to travel from A to B, B to C and C to A is based (within the model) on the average costs of that journey rather than the actual costs, assuming that at some point he returns to his original travel zone. Consequently a commuter can be considered to split a daily parking charge equally between his two journeys to and from work. The average one-way costs in our example are for A to B the cost from A to B + ½ (parking taxes at A + parking taxes at B); for B to C the cost from B to C + ½ (parking taxes at B + parking taxes at C); and for C to A the cost from C to A + ½ (parking taxes at C + parking taxes at A). In exactly the same way in the model we distribute the average parking tax over the two zones between which a trip is currently being made. A charge is thus imposed on all trips leaving a zone in the restraint area as well as on those entering the zone. A parking tax of 20d means in modelling terms a charge of 10d in each direction on the required zonal links. No account is taken within these models of a varying rate according to the duration of stay; it charges a fixed amount on all trips irrespective of their time of arrival or departure.

This does not mean that the parking charge policy is incorrectly represented, but it does mean that the setting and interpretation of any given charges set within the model requires additional care. The equilibrium flow models used in this study represent the mean expectation of conditions over an averaged peak hour at some point in the present or the future. Parking charges are frequently time dependent, and certainly the length of time that people spend in a given parking spot conditions both how much they pay and how much use is made of that spot. A special study was carried out to bridge this gap between practical behaviour on the ground and the less-readily grasped abstractions used in the traffic restraint modes.(9) This work allows us (a) to deduce how many parking spaces are implied by a given level of terminating trips predicted by the restraint model, and (b) to convert the "charges" set in the restraint model into revenue/place and mean charge paid by parkers under any of a wide range of different charging structures and parking arrival rates over the whole day.

As we are assessing parking charges as one of a spectrum of different schemes, this additional stage in interpretation is necessary until the "best" levels of "parking fee" within the restraint model have been determined.

Parking schemes are also vulnerable to poor enforcement. This can arise in a number of ways. The restraint of trips which stop for only a few minutes at a point in the restraint area is just as important for the objectives of overall traffic restraint as restricting commuter parking, but it is very hard to enforce fiscal charges on such journeys. A very much more important problem is that of private parking spaces. From the special viewpoint of overall traffic restraint private parking spaces have exactly the same effect as inadequate enforcement of a fiscal parking policy. The net effect of these two loopholes in this type of policy can be a cut by as much as a half of the potential net benefits. The dilution effects of private parking spaces are analysed in some detail elsewhere,[5] and redistributive effects are shown to occur in favour of those who ignore the fiscal charges or who have private spaces to go to.

Pricing point systems charge vehicles at a fixed rate per unit distance for all travel within the restraint area. It might prove difficult in practice to ensure that exactly the same charging rate applied throughout the restraint area, but on the idealised network it was assumed that one exact rate could be set and that this was in effect in each direction on all links in the restraint area. For Coventry a system of points on the ground was designed such that each link in the restraint area had a specific number of charging points on it depending on its length. This worked out to give about 20 points per mile.

A cordon system consists of a ring of charges around the restraint area. Vehicles crossing into or out of this area then pay a fixed rate for entry to or exit from it. Unlike a supplementary licence system, no restraint is applied to interal trips within the area: and unlike the pricing point system described no account is taken of the length of the part of a trip that lies within the restraint area. However previous research[1] has showed that this policy can be as effective as the other schemes, and the implementation costs are likely to be considerably lower.

The modelling of these two policies is easier than that for supplementary licences or parking. The tolls in the model represent the charges at the cordon or link involved, and the number of journeys made by each road user is immaterial as at each time a charging point is crossed, the fixed charge is incurred.

Policies were simulated in effect on an area of about 3.5 square miles for all these networks (Coventry and idealised). In the case of Coventry this area covered the "railway triangle", a region in the centre of the network bounded by railways and containing over 40% of all the employment in Coventry.[2] This area is not symmetric but as suggested by its name is triangular in shape with a 'height' (N/S) of about 2½ miles and an effective 'base' (E-W) of about 2 miles, and is shown in Figures 1c, 1d.

Physical methods of restraint were also considered in additon to fiscal restraint policies. On the idealised network the capacity of one ring road was increased to give an indication of the effects of a high grade inner ring road. The reverse policy was investigated on the Coventry network. Access in to and out of the railway triangle was cut back to only the eight most congested roads, and the overall network capacity thereby severely reduced. This scheme was intended to show the potential effect of introducing an extensive bus lane and priority system - these restrictions not applying to public service vehicles - or other restrictive management schemes aimed at keeping peak traffic out of the central area. Such a scheme is unlikely to be as efficient as fiscal restraint, although possibly more effective in terms of reducing congestion, due to the heavy cost of pulling expensive and scarce capacity out of effective use. Almost every private and goods vehicle journey in and around the affected region suffers a penalty either through longer journey distances and/or increased congestion on certain links as the restraint is being applied through delay. With a fiscal restraint scheme this applies only to a minority of travellers. In practice bus lanes would be introduced if the bus flows were high enough to justify a separate lane. There are very few roads in Coventry where this would be true and so this collar restraint scheme was unlikely from the outset to prove worthwhile for Coventry's special conditions.

Benefits to bus passengers and goods vehicles were calculated by comparing pre-restraint journey costs with post-restraint. It was assumed that goods traffic did not respond to fiscal charges but only to changes in network conditions and that public service vehicles responded neither to fiscal nor to network changes. Goods vehicles would in practice respond to fiscal charges at least to a limited extent, if only by altering the time of day that deliveries were made.

2.3 Choice of policies for assessment

The results of applying different forms of restraint to the idealised network are given in (1). These results are based on an overall p.c.u.[4] trip demand elasticity of 1.0 and a congestion level roughly equivalent to Coventry in a 1967 peak-hour. The selection of policies for assessment in Coventry was based on these results, which also provide for useful comparisons between the two situations. The idealised network results suggested that restraint area size is of critical importance and that i the more congested parts of the network are included there is little point in extending control over any wider area. Parking tax schemes showed a fair degree of tolerance to the charge selected provided that all restraint schemes were fully enforced. Broadly speaking all of the fiscal restraint schemes could be tuned to give comparable results. A larger benefit could be obtained in increasing network capacity than by fiscal means, but even greater benefits are available by running restraint schemes in conjunction with such an increase in capacity.

The initial restraint studies on Coventry (1967) covered the three fiscal restraint schemes and in addition a supplementary licence scheme. The objectives at this stage were:

1) to determine whether each of the fiscal schemes could obtain equivalent benefits on the actual network in comparable conditions, and to check whether the guidelines from the idealised network studies were applicable in this case.

2) to test the order and shape of the benefit-revenue curves derived for the idealised network (Fig 8) and in particular to see whether parking tax schemes retained their tolerance at different charging levels, and whether this scheme still required the highest revenue of all restraint schemes to reach its optimum benefit.

3) to test the effects of changing the size and shape of the restraint area. The pricing point system was selected for this as it is generally more sensitive to these decisions than the other policies.

4) to test the effects of reducing network capacity, and to check if the results were consistent with the increase in capacity assessed in Reference 1 and demonstrated by Figure 8. Figure 8 shows some of the charge at which benefits were achieved for each policy, and indicates the factor by which current fuel taxation levels have been multiplied for the appropriate policy, namely fuel tax variation.

2.4 Results for Coventry (1967)

The requirement for a very high degree of convergence of the demand and congestion models used has already been described and it sometimes proved necessary to obtain the final benefit and revenue and loss figures by extrapolating the model's results over a short range by using the convergence characteristics of the various indices of performance of the network. A few additional runs were made to verify that the accuracy of such extrapolation Table (1) summarises the final estimates and results of the schemes modelled on the Coventry network. (Where a figure includes any component that has been obtained by extrapolation or otherwise estimated, it is marked by an '*' in Table 1).

Two results are given for the marginal social cost pricing scheme: in one, all traffic was assumed to respond elastically both in routing and in travel demand and in the other this was true only for private vehicles the remainder retaining the same level of demand and pattern of routes under all changes produced by restraint. The first gives the true greatest benefit that we can obtain by fixed means and the second the best under the additional constraints that we have imposed. The former results were obtained directly from both a single-link model representation in which the flows

are not conserved at the nodes nor are any re-routing effects considered, and for a conventional mode. The two results agree fairly well confirming a previous conclusion that for trip demand elasticities greater than 0.5 an independent link model[6] can be very effective.

The results from these two models suggest that only slightly more benefit can be obtained from the 1967 Coventry network than from the idealised network used for earlier studies, and that under the restrictions normally imposed, the optimum benefit that can in practice be reached is only about 70% of the theoretical optimum (The difference between the Coventry and idealised networks results is somewhat greater than the figures would suggest since the former are - in 1967 pounds and the latter for 1968 pounds). Using a comparable definition of net benefit to allow comparison of idealised and 1967 networks, Figures 9 and 10 summarise these results. The direct comparisons of 1967 and 1981 forecasts are shown in later diagrams.

Only one of the practical restricted area policies achieved a net benefit greater than 26% of the "practical-theoretical" optimum when assessed on a similar basis to the marginal social cost pricing scheme. Although this was worse than the equivalent idealised network schemes, where benefits of between 55-60% of this potential maximum were reached, it is partly attributable to the 20,000 pcu goods trips - out of an overall total of 74,000 pcu - which were taken to be inelastic in both demand and routing, thus reducing the effective efficiency of the pricing policies

All the fiscal schemes could be tuned to derive benefits within a range 50-60 pounds per hour, as was found in the case of the idealised network. For both situations the final toll revenues required to produce the maximum net benefits as each of these latter schemes covered a wide range of values. For the idealised network pricing point and cordon policies needed least revenue to be levied and parking taxes the highest. For Coventry (1967), parking taxes, pricing point systems and supplementary licences only required a low revenue but in this case cordon charges levied a much greater amount.

The main causes of this reversal are the different characteristics of travel demand over each network and the difficulty that private vehicles have in finding alternative routes through the unfavourable network around the restraint area in Coventry. The trips affected by the restraint policies can be divided into three types - through trips with both origin and destination outside the restraint area but at some point crossing into it, internal trips with origin and destination inside the area, and access trips with either the origin or destination - but not both - inside the area. The total number of trips which travel in the restraint area is

then given by T + I + A (where T = through trips, I = internal, A = access). The restraint policies considered in this report affect these classes of trips in different ways. The cordon policy extracts a toll from each through trip on two occasions - (entering and leaving the restraint area) - from each access trip on one occasion and internal trips are not charged at all. Parking taxes on the other hand charge each internal trip twice - (a toll is set on all originating trips to reflect the average parking tax) - each access trip once and through trips are unaffected. Pricing point systems and supplementary licencing charge each type of trip at the same rate either in total or per unit distance - (and might therefore be put forward as inherently the 'fairest' schemes).

The idealised network has more internal than through trips in the restraint area and parking taxes required the highest revenue when yielding to the highest benefit. Coventry has more through than internal trips and the cordon policy required the highest overall revenue. In Coventry's case there are other associated reasons which would lead to high cordon charges - the through trips being longer than the average and hence requiring higher tolls to give a set level of response - but broadly speaking the level of charges required by alternative restraint schemes can be found from the ratios of through to internal to access trips. This finding is limited in value as the process of aggregating trips into zones causes the loss of interzonal trips from our calculation, and so the definition of 'internal' trips depends on the level of aggregation chosen.

On the whole most of the fiscal schemes had flatter benefit-revenue curves for Coventry (1967) than the idealised network, showing a fair degree of tolerance to the actual charges set.

The size of the restraint area once more proved critical, particularly when it was made very small. (Figure 10) Various pricing point systems were tried over 3 areas of Coventry; a small central area of about 1 square mile enclosing the Southern end of the railway triangle (Fig 5a), the railway triangle (Fig 4a) and a larger area of over 4 square miles which extended the North-Western end of the triangle (Fig 5c). The smallest of these areas obtained no net benefit for any of the charges tried, and the best result was a benefit of about 300 pounds per hour less than that obtained for th railway triangle. The largest area produce a best result of just over 10 pounds per hour greater benefit than the railway triangle and supports the deduction already drawn from the idealised network that there is little to gain from this sort of scheme enlarging the restraint area once the main congested regions have been included.

The overall efficiency of pricing point systems can be improved in several

ways. The non-symmetric shape of the railway triangle may have prevented this policy from being as efficient as it could be. Other policies are on the whole unaffected by the geographical shape of the boundary whereas extensive point systems penalise in some directions more than others - in this case North-South ones. Over the symmetric larger area this policy performs no better than the railway triangle scheme, but in the case of Coventry (1967) this is due mainly to the lack of congestion in the new restraint areas. The uniform charging rate reduces the overall efficiency of point pricing schemes. This can be seen from the results for the optimum pricing point system in the railway triangle. The tolls in the railway triangle obtained from setting optimum marginal social cost charges over the whole network were set as a restraint policy in their own right. The final benefit was considerably greater than that obtained by every other restraint scheme and was as high as 40% of the best possible for the whole network. Pricing point systems can therefore be highly effective if the charging rate is varied to suit the particular congestion conditions and travel patterns present in the area.

Both increasing and decreasing network capacity can also be considered as restraint policies or their complement. On the idealised network the pcu capacity of the third ring was more than doubled.(1) This is roughly equivalent to the construction of a high-grade inner ring road. The benefit produced by this change alone was over 60% higher than that for the best (optimum-toll) scheme on the same network. The opposite effect was investigated on the Coventry network. Access into and out of the railway triangle was cut back to only the eight most congested roads thereby severely reducing the overall network capacity. (Figure 7d).

Although this form of physical restraint produced a substantial net loss, it was possible to alleviate this slightly by operating a parking restraint scheme in conjunction with the reduction in network capacity. But the benefits secured by the restraint scheme was less - after the change in network capacity - than before, in line with the results obtained for the idealised network.

Table 1 lists the component benefits to private and goods vehicles, and trips transferred to buses. The loss-revenue curves for goods and private vehicles are very similar in shape at all but high revenues where goods vehicles suffer disproportional losses. This is likely to be caused by assuming that goods traffic would not respond directly to fiscal charges, and would remain on the same routes before and after the introduction of restraint measures. The private vehicles can adapt their routes within the model so as to avoid the worst of the tolls if it is to their overall advantage and this allows them to use the network more effectively. The 1967 scenario results are given on the same diagrams as the 1981 scenario results, to show how the effects of increased congesion (and in this case virtually terminal

congestion) compare with the lightly-congested "1967" conditions.

The changes in overall average network speed for the fiscal schemes is only about 10%. This average includes several rural roads and high capacity dual carriageways which were not congested in 1967 and show little change in speed after restraint. 80% of the roads in the urban areas of Coventry show rises in speed of between 13 to 27% for the levels of charge yielding maximum benefits for each type of policy, the other 20% showing little or no change. The parking policy generally gave rise to higher speeds over the entire urban network, and compares strikingly with the considerable amount of re-routing by the road users in their attempt to avoid the restraint areas of other policies and increasing the congesion on some types of roads. However these latter policies also gave the largest increases in link speeds on other roads. With the best collar policies identified-ie collar alone and collar + 10d parking taxes - the average speeds are lower after restraint than before as would be expected for any scheme where restraint is imposed by delay. On urban roads the reductions in speed vary from 10 to 40% and even on dual-carriageways speeds drop by up to 15%. Broadly speaking fiscal restraint policies in the railway triangle increase speeds on urban roads by about 15% and physical (collar) schemes reduce the speeds on these roads by about 30%.

The reduction in vehicle mileage travelled over the network produced by restraint is important to both the environment and to traffic engineering requirements. No significant change in vehicle mileage occurs in the outer regions of the network or on the dual carriageways, but on most of the urban roads there is about 10% less traffic for the best fiscal restraint policies and 5-7% for the equivalent physical (collar) schemes.

The overall case for restraint in Coventry in 1967 was limited, as these results confirm. A mild policy of parking restrictions would have been quite adequate to contain congestion at that time, and has been adopted since 1967.

The very fact that only small restraint charges were needed made this stage of the study more effective in testing the new modelling procedures. These models were forced to discriminate consistently between marginally different situations and so were subject to stringent series of tests of their intrinsic consistency and utility, until these conditions were satisfied.

2.5 Modal choice implications

Only the results for goods and private vehicles have so far been discussed: and benefits obtained by bus travellers are not considered. Approximately 27,000

trips were made using Coventry's public service vehicles in an average peak hour during 1967. All these passengers stood to gain from the implementation of fiscal restraint schemes - as long as public transport fares remained unaltered - due to reduced congestion and consequently more efficient bus services. The net benefits obtained by these travellers were calculated by comparing journey costs before and after the application of a particular restraint scheme.

Two different frameworks are used to assess restraint effects on bus travellers:

1) A modal transfer situation whereby only those travellers forced off their private vehicles as a result of the application of a particular restraint scheme were assumed to transfer to public transport (bus).

2) An optimistic view where some further travellers in addition to those changing mode began to travel by bus. This was simulated by assigning a trip demand elasticity of unity to existing bus passengers, and in most cases produces more bus travel than for Case (1). This interpretation induces double-counting, as the cost function for traffic has already assumed a proportion of bus traffic and passenger levels, and was used solely to assess the appropriate potential size of benefits to bus travellers. Model (1) is used subsequently.

Several assumptions were made when these situations were formulated as models

i) The value of time of bus passengers was taken to be 57d per hour in 1967.[10] (Clearly this applied only to model (2)).

(ii) The average time at each scheduled stop for a two-man bus was taken to be 10 secs.[11] One-man buses were not considered as they were not introduced in Coventry until 1968.

(iii)It was assumed that there were on average 5 scheduled stops in every mile of bus route.

(iv) Fares were assumed to be fixed at the rate of 3.5d per mile. This figure was obtained by factoring down 1970 rates to 1967 rates.

(v) All restrained trips previously made by private vehicles transferred their pre-restraint journeys to bus with an averaged private travellers' value of time of 70.0d per hour.

(vi) Elasticity of trip demand of current bus travellers is taken to be unity. (again, this applied only to model (2)).

(vii)It was assumed that all the restrained trips had bus routes available as an

alternative with respect ot the total generalised costs of their journeys. About 10% of the mileage of the entire network contained one or more bus routes, which means that the benefits calculated will be optimistic. The assumption is reasonable as those routes most affected by the various restraint policies occured in and around the railway triangle and it is on these roads that the majority of the bus services run.

Assumptions (i) to (v) led to behavioural cost functions for modelling public transport of:-

Current bus travellers: $$\text{Cost/mile} = 1.46 + \frac{23.8}{\frac{1}{\frac{1}{v} + S/360}}$$

$$= 1.78 + 23.8/v \text{ p./person}$$

Retrained private travellers: Cost/mile = 1.78 + 29.2/v p./person

After the restraint scheme has been simulated, the difference between the pre- and post-restraint situations determines the number of vehicles forced off the network. This can then be converted to the number of people by assuming an occupancy of 1.41[2] people per car. The total generalised cost for each possible journey was calculated for the behaviour cost function:-

$$1.78 + 29.2/v + 0.0/v^2 + 0.0/v \quad \text{pence/mile}$$

For model 2 the total number of bus trips were set to a value of half of the initial number of private vehicles trips for each journey. The benefits accuring to transferring travellers was calculated from the 'before and after' equation for consumer benefit, $\frac{1}{2}(q'+q)(-c'+c)$, and as the amount of bus travel was here assumed to remain constant, only the values of c and c' altered for those who were initially using public transport.

The fare revenue from these transferring travellers can also be obtained, and the benefits to bus travellers calculated directly from these two skim trees.

To avoid any possible confusion or double counting, only the results of the forced modal transfer model are shown in Table 1, but the benefits derived from both the public transport situations are comparatively close and approximately linear with bus and private revenue, particularly at high revenues. At low revenues a trip demand elasticity of unity gives a slightly greater benefit than that obtained from modal transfer, but rarely greater than 10%. The benefits become still closer at high revenues. These results are to be expected since the benefit to bus travellers is directly connected to the reduction in congestion and hence revenue obtained. It may be calculated that very little extra benefit if any may be gained by allowing

those people priced off private transport to transfer to public transport in the low congestion conditions of 1967.

The restraint policy which cannot produce extra benefit for bus travellers in either situation is, as might be expected, the collar restraint policy. The private vehicles remaining on the network have increased in number in relation to the congestion, to the point where bus travellers also suffer, and but for the case where a 10d parking toll is employed, public transport travellers suffer a definite disbenefit. The other restraint options generate some benefit for bus passengers, although generally once again small due to the lack of congestion in Coventry in 1967.

The extra revenue obtained from bus passengers resultant from restraint on private vehicles was also calculated and found to be negligible. This was only to be expected as there was very little increase in average network speed due to the lack of congestion. Consequently the bus service would appear to be little more attractive after restraint than before.

Goods trips were added to the private car trips to provide an aggregated trip matrix for perturbation modelling. Having obtained an equilibrium with these aggregated trips and an aggregated cost function the matrix and flows were split up again by applying a constant factor. The goods traffic was then assumed to remain fixed for restraint modelling, and the restraint tolls to be perceived only by private users. The goods traffic may therefore reduce the capacity of the network available to private cars. The benefit to goods traffic, as a result of reduction in congestion due to restraint, was evaluated directly by comparing goods costs before and after restraint just as was done for public transport.

2.6 Comparisons with other work

Several further studies have been made on an idealised network since our initial assessment[1] of alternative restraint schemes and these can be related to the results given in this report. They include

1) the effect of selective restraint policies which do not directly charge all vehicles. It is difficult to visualise how schemes such as parking taxes could be imposed on all vehicles within the restraint area.[5]

2) the effect of imprecise appreciation of travel costs. We have arbitrarily chosen a reasonable value - the marginal cost - but some travellers may base their travel decisions on other assumptions.[12]

3) the effects of splitting travellers into separate categories, each with their

own perceived behavioural cost functions. This is similar but not identical in effect to the differentiation between goods and private vehicles in the 1967 Coventry model, but for the idealised network each group was allowed to respond to changes by varying both routes and the number of trips made.( )

The overall benefits from the idealised network derived by the optimum parking tax scheme for different ratios of charged to non-charged trips is not directly proportional to the ratio of charged toll uncharged travel but a small extra benefit has been found (5) partly due to extra trips made by the uncharged trips and partly due to the more efficient road utilisation of the idealised network achieved with a blanket charge policy. If one assumes that parking taxes affect only half to two-thirds of the trips ending in the railway triangle, the benefit derived from this scheme will now be about 100-120 pounds compared with over 150 pounds when the taxes are applied to all the pcu's. This estimate is based on the idealised network results.(5)

This was checked using the 1967 Coventry model for the case when only half of the trips were subject to charges initially. The results are given in Table 1 and show that the benefit derived has now fallen to about 120 pounds. In view of the substantial test for the effect of splitting up the travellers into groups with high and low values of time and operating costs, some deductions can be made from work on the idealised network.

The total benefits obtained by the two different groups of trips is about 25% lower than that forecast for a single averaged group. If this is applied to Coventry the overall benefits would be expected to be about 250 pounds. If the reduction in the sensitivity of the travel demand due to inelastic goods traffic is estimated the value rises to nearly 300 pounds per peak hour or about 50% of the theoretical maximum. The general agreement between the deductions from the idealised network and the 1967 Coventry Scenario is reasonably good, and as our results so far have been for a peak-hour, the idealised network results may be used to give some indication of the results likely in off-peak hours. They suggest that negligible benefits would be derived in Coventry under 1967 off-peak conditions.

2.7 Review of the Coventry 1967 scenario

The final link flows and zonal demand for the optimum solution - (ie at the charge which gives the greatest overall benefit) - for each restraint policy has been compared with the pre-restraint solution, and against the optimum solutions of the other restraint policies. The results refer only to private vehicles as all other traffic is assumed not to respond to restraint either by changing route or by altering the number of trips made.

Although the effect of restraint on the overall trip demand in 1967 is not large - no more than 12% of private vehicles were priced off the network for any "optimum" policy - the individual link flows or demand from certain zones can show very significant differences from the pre-restraint state. This suggests that large numbers of road users are finding alternative routes over the network once restraint has been introduced, and that some local effects of restraint charges are far greater than is immediately apparent.

Supplementary licencing produces a general decrease in link flows of about 5-3% outside the restraint area - (except for one area to the East with a slight increase in congestion) - but with larger decreases of up to 30% in the central area, 21% to the North of the railway triangle and 18% on the inner ring road. By comparison parking taxes produced steadier effects with about 5-8% decrease in congestion around and to the North of the restraint area but with larger decreases of 30% in the central area. Traffic on the inner ring road was reduced by only 8%. This would probably consist of through traffic, affected by supplementary licences but not parking taxes.

The equivalent cordon policy gave larger general decreases of 15-20% outside the restraint area. However just South of the railway triangle there was a 50% increase in traffic flows made up from road users avoiding the restraint area. Inside the cordon there was a large decrease in flow (50-55%). Similar results were obtained with the larger cordon with a smaller increase of 6% in flow to the South. The reduction from a 50% increase to this smaller figure is due partly to the by-pass routes being cut by this cordon, and the smaller decrease inside the cordon is attributable to the increased travel demand within the restraint area.

The area pricing point policy severely curtailed traffic in the railway triangle and produced the most uniform decrease in traffic flows inside the restraint area of between 30-40%. Outside this area there were small decreases in flow of 2-3% with an increase of 6% to the South of the railway triangle.

The results are broadly in line with those of the circular network and with what one would expect in practice. The region just outside the restraint area either becomes more congested than before or the fall in congestion within the area is less than in other parts of the network. Supplementary licences and pricing point systems hit traffic in the restraint area comparatively hard, parking taxes less so since through trips are uncharged. The cordon policy produced the greatest diversion around the restraint area and to a certain extent encouraged internal trips within this area. Both road flows and travel demand were reduced most by the cordon scheme.

Changes in travel demand from pre- to post-restraint conditions for supplementary licences, pricing point charges and parking taxes all gave comparable overall results. Zones within the railway triangle restraint area were the most affected with about 5-11% of private vehicles restrained. Whilst in all other areas other than the sub-region travel demand dropped by only 3-4%. The cordon policy priced more traffic off the network than other policies - (to derive its optimum benefit) - with about 18% traffic restrained in the railway triangle, and an overall 10% for the rest of the city although this last figure includes larger individual increases and decrease in travel demand. Travel to and from the subregion was little affected. Almost all the restrained trips lay within the boundaries of the City.

Parking taxes reduced demand from individual zones inside the railway triangle by 3-7% more than supplementary licences. Licences reduced demand just outside this region by 0-3%. These differences are small, but parking taxes would be expected to have a more severe effect on travel demand within the railway triangle as they affect only those trips with origins or destinations there. Supplementary licences affect all types of trip: through, internal and access. The area pricing point system and supplementary licences produced similar results inside the railway triangle except for one large zone on the western boundary of the restraint area. Supplementary licences reduced the trips from this zone far more than the pricing point system. This is to be expected since a charging system based on a levy per unit distance will affect travellers starting near the boundary from leaving the restraint area less than a charge for entry to the area.

The cordon policies reduced overall congestion considerably more than other policies. As cordon size increased so also did trip demand within the restraint area (by 7% in one case) with greater reductions outside this area (14% in the same case). No significant difference in the travel demand in the sub-region was found between the two cordons.

If the "optimal" cordon were used as a reference level one might expect a greater decrease in travel demand than would be found for other restraint policies. Some zones just outside the restraint area show a greater reduction than average, these zones being the hardest hit by a cordon policy. The effect on zones inside the restraint area varied considerably, some showing larger than average reductions and some as much demand with a cordon as with other policies. One would expect the major differences in demand to occur in this locality, and some of these variations are probably due to an increase in internal trips - (railway triangle to railway triangle) - for the zones where cordon and other policies predict the same levels of travel demand. These trips are affected more by non-cordon policies.

The overall changes in travel demand are less visible than the changes in link

flows. Some of these differences are due merely to the varying congestion levels corresponding to each different "optimum" policy, but none give rise to unreasonable or remarkable changes.

The dangers of drawing direct comparisons between idealised and Coventry networks has already been discussed but several conclusions can be drawn from the results for each network both individually and in conjunction with each other.

1) The major differences between alternative restraint schemes lies in the toll revenue required to reach an optimum benefit level and not in the benefits themselves.

2) The level of charges required by a particular scheme is closely related to the ratios of through to internal to access trips over the restraint area, and can usually be expected to lie within the range of 20-80% of total average journey costs over the urban area.

3) The benefit derived by a practical restraint scheme applied over a restricted area can be as high as 50-60% of the optimum possible for the whole urban area. If goods traffic is assumed to be inelastic and to be treated separately from private vehicles the benefit can fall to 10-25% of the optimum.

4) Moderate changes in the overall capacity of the network - (either increases or decreases) - can have a greater effect on the traffic than any fiscal restraint scheme. Where a fiscal restraint scheme is implemented in conjunction with a change in capacity, the scheme has less impact <u>with</u> the capacity changes than without them.

5) The shape of the benefit-revenue curves on a practical network are likely to be flatter than indicated by the idealised network results, primarily due to different levels of trip demand elasticity found in practice for certain trip categories. Pricing point systems generally give sharper benefit-revenue curve than other fiscal restraint measures.

6) The geographical shape of the restraint area can be important. Severe distortions in symmetry or match to congested regions may adversely affect any fiscal restraint policy, but particularly pricing point systems.

7) The size of the restraint area is important. If too small an area is chosen it is easily avoided. Provided the main employment districts are within the restraint area there is little to be gained by enlarging it.

8) The Coventry (1967) figures were grossed up from the evening peak hour simulated to an annual figure, by assuming four peak hours per day and a five day working week. The total estimated annual benefit is of the order of 0.2 million pounds in 1968 pounds

9) The effects that differing levels of bus service had on mean bus journey speeds in Glasgow have been measured by TRRL.[14] This work showed that comparatively large changes in the level of service were required to have any significant effect on the speeds - roughly a 10% increase/decrease in the overall number of buses on the network gave a 2% increase/decrease in mean bus journey speeds. Assuming resources remained constant, if extra travellers started to use this mode the level of service would be effectively reduced, adversely affecting journey times. However as the reduction in overall congestion in Coventry was small (and also by implication the number of permissible extra bus travellers) it is thought unlikely that there would be enough travellers changing mode to significantly alter the level of service.

Other studies in Glasgow derived a relationship between the overall distance travelled on the network by all vehicles against mean bus journey speeds. The results are only applicable to the centre of Glasgow but suggest that a 4% drop in total vehicle mileage would give rise to an increase in mean bus speeds by roughly 2% in Coventry. The estimate of the overall benefit derived by bus travellers using these figures approximately agrees with those predicted by the model, if bus travel is examined in further detail.

10) These 1967 figures do not include administrative costs of enforcement and operating of any of the restraint schemes. This suggests that the administrative costs of equipping vehicles could be as large as the net benefit obtained for this measure in the 1965 scenario. By 1971 the lowest production cost estimate of vehicle equipment was put at about 2+ pounds per unit. Taking the average annual cost of equipping each vehicle as 1 pound per unit (demonstrating the flow-on real costs of such equipment) the annual cost would be about 0.17 million pounds for all vehicles owned by residents of Coventry and the sub-region before allowing for visiting vehicles.

11) Traffic conditions in this "1967" Coventry scenario were not congested enough to justify any sophisticated restraint system. This is no longer true for the extremely congested "1981" scenario. Although parking and pricing point systems can perform well, the parking controls must be effectively enforced and pricing point systems must be applied over a slightly larger area than parking and also be operated with a flexible charging pattern to achieve the same level of benefits as parking within the uncongested "1967" conditions.

The 1967 scenario provided a useful framework for setting up and testing out equilibrium models in a fairly realistic context. As the level of congestion was not high, the ability of the models to respond to tiny policy variations was put to a stringent set of tests. Due to the small scale of the benefits identified,

there is little point in assessing the restraint shifts in environmental, locational, or social terms. These issues will be pursued in later sections when a more suitable scenario has been put forward for more serious application analysis, in constrast to the model assessments appropriate to the simulated 1967 levels of congestion.

3. A "1981" SCENARIO BASED ON COVENTRY

The Coventry Transportation Study Team set up a range of alternative future situations to consider possible transport plans.[2] For a target year of 1981 a forecast of traffic demand was constructed which exceeded the probable capacity of the network without new construction. The reconciliation of this potential ("unrestrained") demand forecast with the road and public transport system would require either road construction or traffic restraint (were the potential demand to arise by the target date, or indeed later). Such forecasts of 'excess' demand are a normal intermediate stage in the construction of a range of forecast situations where new proposals, transport capacity, and travel demand are held in balance. In order to construct an effective scenario of a congested future condition in a city, this initial 'potential demand' pattern has been picked out, before the completion of this planning design process.

In precisely the same manner as a "1967" scenario was built up from the CTSG forecast of unconstrained demand for that year. The network of roads outside the city boundary was drastically pruned, many zones aggregated together, and a network and zone pattern similar to that used for the "1967" scenario was produced (see figure 11) for the network, and the zone boundaries in the city were the same as used for "1967", with an additional 19 zones added, mainly in the sub region.

The effects of this network simplification and zonal aggregation are to artificially intesify the already excessive congestion potential. These were a number of different investment alternatives analysed for Coventry which could have been adopted: the one chosen to provide the base network was the CTS "Highway Option 3", (low investment alternative). The trip matrices for goods, bus passenger, and car journeys were aggregated to match the scale of zonal aggregation, and factored to a level appropriate to a highly congested evening peak hour. The thirteen speed flow functions used were those allocated by the CTSG and are to be found in their report.[2] The range of relationships is from motor-way class to narrow urban streets subjected to adverse traffic light settings, giving a considerable variation in both slope and capacity.

The objective of the "1981" scenario analysis was to compare the relative performance of different pricing policies, and in particular to estimate the likely levels of restraint on trips, the benefits that could be derived, and the effects on other modes of transport and on the environment. No distinction was drawn between the various vehicle categories in the models but allowances were made in the general behavior of the aggregated unit of traffic for a low elasticity of travel demand for goods vehicles compared with private cars. Bus travellers were treated separately from other road users, and rail travel was ignored due to the negligible use made of this mode.

The modelling procedures used, the assumptions made, and the results obtained from the introduction of various fiscal and full restraint policies are described for Coventry in the version of 1981. These policies considered included supplementary licence, parking, cordons and road pricing schemes together with some mixed restraint policies and fuel considerations. The RRLTAP System was used to develop and to apply the appropriate models for this second scenario, although the conditions describe as "1981" are, due to the manner of their generation, more likely to be suitable to a 1990 date.

The assignment and re-routing of trips over a network requires some mechanism to be set for route choice and it is assumed that travellers act to minimise their perceived sum of vehicle operating time and direct money cost on a link-by-link basis. The sum of these link costs on a minimum cost route between two zones in the network define the inter-zonal costs, and changes in these inter-zonal costs define the changes in the number of people wishing to travel between the two zones.

The perceived behavioural cost function for all consumers and all links was derived from TRRL 1970 data collected by R F F Dawson. The road users were assumed to perceive their net operating, and not their full average, operating costs. These are for each vehicle category:-

Private:	$0.71 + 41.0/V + 0.000057V^2$ p/km
Light van:	$1.00 + 56.5/V + 0.000073V^2$ p/km
Other goods:	$2.37 + 59.6/V + 0.0000016V^2$ p/km
PSV:	$2.38 + 38.8/V + 0.0000150V^2$ p/km

If we assume that the traffic composition observed across 1967 screen-lines hold for 1981, we have 82% Private vehicles, 15% Goods (of which 55% are light goods vehicles), and 3% PSV. Weighting the above functions by these amounts, we have a final aggregated total of:

$$\text{Cost} = 0.89 + 53.5/V + 0.000059\ V^2$$

Changes in the demand for travel between each pair of zones were determined by the models in a very similar manner to that used for the "1967" scenario, using the inter-zonal costs of the final base assignment, the appropriate initial trip total, and an assumption regarding the behavioural response in trip demand elasticity of unity - that is a 1% rise in costs produces 1% fall in demand - whilst goods vehicles were taken to be inelastic in response to travel cost changes. This gave an overall demand elasticity of about 0.8 for the traffic flow when aggregated together.

Analysis and simulation then followed the same path as before, in two stages, the pre-restraint or base assignment was determined and then using this solution as the initial state, the post-restrained states for each of the various policies were found and evaluated. A full description of the technical aspects of these models can be found in references (4), (5) and (6), although the precise details of their use in this situation required some slight modifications to the convergence precision accepted in the iterative procedures.

One result of the excessive congestion intentionally imposed on the "1981" scenario was that the oscillations of consumer surplus and revenue from the restraint schemes did not settle down with the same consistent precision of the "1967" scenerio models. As a result the upper and lower error bounds of the "1981" results are approximately £500/hr, and so the convergence bounds are of little practical use for comparative analyses. The average point between the forced adjustment position and the end of the iterations is always considerably more stable than the error bounds: the reproduction of smooth curves connecting large charges to zero charge options demonstrate this phenomenon. In previous work we have referred to the error bounds as "error bars", leaving the misleading impression that upper and lower bounds are synonemous with standard error estimates. This potential confusion must be removed if the results presented here are to be assumed correctly.

3.1 A review of the policies simulated

The same range of policies were simulated for "1981" as were modelled for "1967", and a number of further policies added. Parking charges, road pricing, supplementary licensing, and cordon charges were all covered. In addition the effects of fuel tax variations and one-way cordons were examined. The most interesting situations are those where restraint policies are carried out in pairs; the best example is that of parking policy in addition to road pricing or supplementary licencing. Such joint price variation studies are inevitably time consuming, and it would be highly desirable for new algorithms to be developed on a sound theoretical basis to guide this type of investigation.[14]

Although this study has demonstrated that equilibrium methods can provide a coherent and consistent analytical framework for appraising detailed policies for traffic restraint, the cost and effort required to run the models can be considerable and even if this cost could be cut to a negligible level, considerable manual effort is required to specify and set up each variation on each policy at the detailed level. It is the latter process that needs analytical support, and recent developments in the application of separable convex programming to transportation networks provides every indication that such sophisticated constrained optimisations could now be handled analytically.

The results for each policy studied are given in Tables 2, 3, 4, 5 and 6 in terms of costs, revenues and benefits and illustrated in Figures 12 to 21. This summary form of presentation cannot adequately represent the complex relationships between each policy, and the structure of the different travel demand shifts. Table 7 shows how travel demand alters with changes in restraint policy, and in later sections other aspects of travel demand intensity are displayed in visual form. Desire line plotting is used to show how the intensity of demand for travel is affected by restraint: geographical plots of trip making changes and generalised cost of access charges show how the detailed georgraphical distribution of impacts can differ considerably between different restraint measures that may give comparable overall benefits and costs. The environmental impacts of traffic restraint form a further substantial section, and the use of environmental factor forecasts of this kind are shown to be well matched to the models in use, although the results raise more fresh questions than they answer.

The results presented here, together with the visual forms of display, are a demonstration of the technical feasibility of applying traffic models to short run, fine grained transport policies, and the general utility of the results. Had the basic scenarios been matched to Coventry, rather than taken as situations in their own right, then the results would have been expressed in detailed terms as an extension of the Coventry Transportation Study. Unfortunately the modifications introduced (generalised cost, modified zone structure, altered networks etc) make this rather difficult, and the net effect of the "1981" Scenario could but be described by suggestions that the "1981" scenario as used here could possibly be re-interpreted in terms of a 1990+ situation in Coventry, if further modifications were to be added when interpreting the results.

A natural next stage of the delinatory pilot demonstration of the application of equilibrium analysis would be to add the effects of regulation to the battery of policy measures under discussion. The enactment of the Heavy Commercial Vehicles Act (1973) provides powers to UK Local Authorities to set up systems of long

routes to which certain types of heavy vehicle could be restricted. As the prime objective of such a measure would be environmental, the environmental impact forecasting methods developed here would be of special value and an exploratory study of this kind was completed in collaboration with the Greater London Council, in order to assess the resource costs and environmental benefits that might be derived from a system of lorry routes, and is discussed elsewhere. ( )

For policies considered one at a time it was found that with the exception of parking taxes the other policies produced approximately the same benefit, but that the parking policy could raise only about one-third of the best values obtainable by means of other policies. Parking taxes alone cannot be an entirely effective form of restraint in a town such as Coventry without any district concentrated centre of employment, but where offices, factories and schools are dispersed over the whole network. Our basic parking policy applied only to the Railway Triangle and although trips with their origins and/or destinations in this area were effectively restrained, through trips to and from other parts of the city were encouraged by the reduced central congestion. However although this policy did not perform well by its own it seemed likely by analogy to the city on which the "1981" scenario was based, that some form of central parking control would be required in conjunction with a further restraint of a different kind owing to the limited number of parking places available in certain parts of the city. It is also clear that parking was an acceptable restraint policy, and will continue to be used in one form or another. Consequently a selection of mixed restraint policy situations were modelled and results were obtained which supported the view that some central area parking control would be desirable even when other measures were in effect. Graphical representation of reductions in demand for the various policies is discussed later.

The most surprising result is the degree of sensitivity pricing point systems showed to the level of charging on each link. If the theoretical foundation of single link optimisations could be relied on, then one would expect this policy to be the most effective traffic restraint measure, as individual congestion spots can be identified and dealt with by an appropriate toll matched precisely to the local conditions and capacity. Unfortunately however, unlike the "1967" scenario, it proved extremely difficult in practice to find a set of charges which would respond effectively to the conditions of the "1981" scenario in a restricted region. Eventually a set of charging levels on the roads in the railway triangle was found which could perform as well as a supplementary licence or a cordon. But this set is certainly not unique, and there may well exist another set which could perform even better and a later section describes how such another set was found. The extreme sensitivity shown by this policy to even marginally different charges militates strongly against its suitability for practical implementation. Any original set of

charges would have to be continually adjusted to respond to changing traffic conditions in order to maintain an efficient and effective pattern and level of traffic restraint.

While the individual policies are of interest to distinguish between their different degrees and styles of effectiveness, mixed policy restraint situations were modelled to give a greater degree of practicality to the analysis of alternatives. The methods used to model the supplementary licence and parking policies were such that a licence charge of 2*c pence was specified as a parking charge of 2*c pence plus a cordon charge of c pence within the model. As a result the supplementary licence results together with the parking only and cordon only results could be used to construct a grid of cordon plus parking charges. This grid was filled out with explicit simulations of mixed cordon + parking policies at various levels of charge. (Fig 20).

A similar joint variation exercise was carried out for a supplementary licence policy supported by a parking scheme although it is evident that a straightforward cordon policy cannot be precisely equivalent to a supplementary licence + parking policy. The grids thus obtained are described in figures (19, 20) and results summarised in Table 3. Although, as expected, the results were similar to those produced by single policies (other than parking), a combination of cordon 40d + parking 80d gave the best overall result (optimum optimorum) of all the policies. Consequently, while parking restraint is not very significant on its own, its effect as a joint control policy where used in conjunction with another system of restraint is both significant and valuable. This is reassuring, as any practical restraint scheme must operate in conjunction with the parking instrument, and a mixed cordon + parking restraint scheme is therefore the most practical policy studied here. Figure 21 shows the benefit/revenue curve for the cordon 40d + parking charge, as the parking charge varies and the cordon charge is held at 40d. It is clear from the figure that the benefits are extremely sensitive to the parking charge, and that an oscillatory position is obtained. This would indicate that while parking + cordon is a practical scheme to implement, there may be some difficulty in finding an optimum parking charge in practice. The variations in benefit shown in Figure 21 are the direct result of the interaction between the network topology, the pattern of travel demand, and the choice of restraint area: the joint variation of these influences produces these slight changes in net overall restraint benefits. These variations are not likely to be significant in practice, and are of interest mainly for the technical features displayed - ie the responses to geographical and topographical specialisation.

Each individual policy will now be considered in greater detail from an economic stand point, and the environmental and social impacts will then be considered.

The overall economic view would not be complete without some indications of the physical shifts produced by the response to economic changes. As the main area of interest is the Railway Triangle, the speed of traffic flow on the roads inside, outside, and around this district provide a pertinent summary displayed in Figure 22. The elastic aspects of the travel demand response is best expressed in terms of the total traffic flows crossing the boundary of the area, and the variations in travel demand for trips to and from the triangle. These demand variations are shown in Figure 23, and indicate how the relationships between traffic speed and travel demand do not always match too well with each other or indeed with traffic flows in a specified area. Of special interest is the inefficiency of pure parking control measures to affect traffic flows without undue restriction of travel demand - and the acute severity of our version of supplementary licencing in that it produces the greatest reductions in both travel demand and traffic flow for about the same net benefit as less stringent schemes. While this impact might well be a desirable political aim in its own right, it is important to underline the basic economic inefficiencies inherent in this method of achieving such ends.

3.2 Cordon restraint

Cordon restraint is exemplified in this study by the imposition of a flat rate charge for crossing a cordon drawn round the railway triangle (Figures 1d and 7d). Figure 12 displays both "1967" and "1981" scenario results on the same graph: the peaks of the net benefit curves are at very different values, and although the simulated increase in traffic was substantial between the two years, the shift in "optimal" charge is only from 20 to 40d. Part of the explanation of this limited shift is the concentration on the railway triangle. Although the simulated future traffic is more intense it is the peripheral and cross movements that rise most, reflecting the expected growth in leisure journeys, geographical inflexibilities being imposed by the structure of the network and the city. Further factors are the predicted completion of the inner ring road (well on its way at the time of writing), some limited other roadworks, and the installation of area traffic control (which has the predicted effect of raising junction capacity utilisation, and thus the speed flow functions assigned by the Coventry Team). Many of the weak conclusions drawn from the "1967" scenario seem to be borne out by the "1981" results, and pricing cordons once again emerge as an efficient and potentially more flexible restraint system than others considered. To assess cordon policies for an operational scenario, the joint variation of parking and cordon policies provided a good starting point to move from the theoretical results given here to a more realistic and practical scenario and assessment and the robustness of the conclusions has since been confirmed in later studies where physical factors, behavioural cost, and demand level factors were raised.

3.3 Supplementary licencing

The use of a supplementary licence levy as a restraint measure provides a means of influencing journeys entirely within the boundary cordon (see figure 6c), and although the balance of effective charges will produce a severe reduction in the shorter journeys in the area, this may have second order benefits in terms of local environmental gains: a matter pursued in later sections Figure 13 shows how the net benefits respond to varied charges, and the 7:1 increase in optimal licence fee is really a reflection of the acute severity of the scheme in the base year ("1967") scenario, where this strong instrument could not be wielded effectively without risk of reducing network utilisation. As the congestion level rises to "1981" extremes this hampering influence is removed, giving an overall characteristic not dissimilar to that of cordon charging - but once again at a higher charging level. If the two components of supplementary licence impact are treated separately, we obtain parking and cordon policies. Figures 12, 13 merely show that the "parking policy" implied by a supplementary licence is not the best. Figures 19 and 20 examine these issues in greater detail.

3.4 Parking charges

Parking charges become less effective as sole restraint instruments as congestion rises.(5) The matching of Figs 6a with 6b to 6c demonstrates the links between parking, cordon, and supplementary licence controls.

The effects of using parking charges in isolation as a restraint policy are shown in Figure 14. The tolerance to charging levels is typical of this method of restraint when it can achieve full coverage of all trips and full enforcement. The 3:1 increase in optimal charge shows how the most efficient level of restraint is reached at a far earlier point than that achieved by the first two policies. Overcharging simply clears roads to attract new through trips, and it is this second order network effect which acts to reduce the efficiency of each increment of parking charge. A further discouraging point is the low net benefit achievable as a result, and any private parking spaces or lapses in enforcement will cut this benefit by up to half.(5)

This should not be taken to suggest that parking charges are inappropriate restraint measures; simply that they should not be asked to carry the burden alone.

The actual charge levied on each trip will depend on the length of stay. The average annual rates implied by transportation planning models obscure the situation still further, as several trips may use a single space in an hour, and yet appear to be charged the same amount within the model. The charges shown in Figure 14 require

further manipulation before they can be linked directly to a car parking rate. This conversion process has been the subject of a special Markov analysis model, built especially for this purpose.[9]

This model is described elsewhere,[9] and includes conversion graphs to allow parking charges to be linked as a function of arrival and some journey distributions to the mean p.c.u. levy rates used in Figure 15 and throughout this report.

3.5 Area road pricing

The best known version of fiscal traffic restraint policy is that of an area wide system of charging points, permitting an extremely close grained graduation of charging levels from road in response to capacity and demand fluctuations over the area concerned. This policy has a facile simplicity about it which has been perpetuated by a series of overly simplified and sweeping economic discussions. The appraisal of any realistic scheme must be matched to the capacity, demand, and geographical peculiarities of a specific region: as this makes it extremely difficult to draw generalised conclusions, the two key conventional economic analysis assumptions have become (a) that charges may be applied at any level on every link, and (b) that a single link adequately represents an entire network, if necessary on a piecemeal basis. The structure of charges produced by this type of theory[b], for all the roads in a restricted are, has been used to develop an "idealised" charging pattern for the City "1981" Scenario. Table 2 and Figures 15 and 16 summarise the investigation. The simple application of the idealised charges only to roads in the Triangle, produced a large negative net benefit, as might have been expected. The levels of charge were not designed to cater for the dual objectives of balancing road against road and restraint area against the unrestrained surroundings. In order to try to retain at least the relative scaling of charges between roads within the Triangle, the whole pattern was multiplied 2, and then 3 times. The produced a reasonable net benefit of about the same size as by parking charges, and about half the level achieved by both cordon and supplementary licence instruments. If the internal relativities were dropped, and a flat rate charge levied for all roads the net benefits fell to zero, as the high undifferentiated charging rate made diversion round the triangle attractive. It was therefore worth examining an extend area; these results are shown in Figure 16, but are no better.

The best system devised was to use the "optimum" charge predicted by simple theory on all road links in both directions, but to apply the highest charge for the two directions to both directional links. Figure 16 shows that this device is remarkably effective.

The deduction to be drawn from these experiments is that the number of degrees of freedom provided by area point pricing are excessive, when the practical problems of charge settling and monitoring are considered. As the best results obtained are no better than those from far simpler schemes, there is clearly only limited advantage to be gained in such complexities. If theoretical economic studies were to be carried out to analyse realistic area point pricing systems, then the situation could change. However the indications are that geographical peculiarities of an area are likely to outweigh the marginal improvements that might be coming out from an improved theoretical technique for price setting. It is also open to doubt that such fine gradations of charge would be either perceived or practicable. The process of experimenting to obtain reasonable results on the "1981" scenario is of some detailed interest, as it highlights the degree to which heuristic devices were imposed on us by the attempt to use the standard theoretical basis for generating pricing patterns.

Road pricing point policies did not prove entirely satisfactory on the Coventry 1981 network. The previous work on the tehoretical ring-radial network and on Coventry in "1967" showed that such policies could be expected to perform as well as other schemes such as supplementary licencing and cordons, and could produce greater benefits than rail policies in the case of optimum charging rates even when these were applied over restricted access only.

However the first result (Table 2) showed that all flat rate charges per unit distance schemes were uniformly inefficient and failed to derive any significant benefits, and that even optimum charges over a restricted area - the Railway triangle - only derived 40-43% of the benefits attained by the best supplementary licence and cordon schemes respectively.

At the time it was suspected that the reason for the poor performance of the optimum charging policies was the choice of incorrect charges. Many of the links in the restraint area were overloaded and under these conditions the forecast programme[6] for the optimum charges restricted the rate to 31d per mile or less. This upper limit was exceeded on numerous occasions with consequential detrimental effects on the possible attainable benefits.

It was felt that the flat rate charging schemes performed badly because they failed to differentiate between roads which needed restraint and those which didn't. The attractiveness of the longer but faster ring roads in the central area was

eliminated and road users would be forced to find the shortest paths as these were now their cheapest. Thus overloaded links in the central area became even more overloaded whilst comparitively free-flowing or uncongested links around the congested areas were not cheap enough to attract users away from the shorter but slower routes. Other parking policies do not differentiate between links in this way and are only concerned with applying restraint at a boundary of a specified area or on a trip end.

A multi-rate charging scheme was tried. Uncongested links, such as the inner-ring road, imposed a very low charge per mile on road users, whilst other links had a much higher rate. However this scheme only performed slightly better than the flat-rate system, possibly because incorrect charging rates were chosen or were applied on the wrong links.

It was decided that the quickest means of ascertaining whether pricing point schemes could perform adequately was to concentrate on the optimum charge schemes and aim to derive a benefit greater than that from other policies to allow for the slightly unrealistic nature of such a scheme. The Coventry "1967" results show that this was feasible.

Consequently the optimum charge forecast program (TSW39) was extensively amended to allow for overload conditions and the required optimum tolls found for the whole network with no preset upper limit to restrict the charges. A run was then made with those tolls and a benefit derived of 45-50% of that obtained from the best supplementary licence and cordon schemes. Although this was an improvement on our previous results, we were still a long way from our target of deriving greater benefits than the rival schemes.

In theory the effects of road pricing should be somewhat similar to those of supplementary licencing in that all trips made into, through, or around a specified area are penalised by the road pricing charges. To this end a comparison was made of the vehicle miles by link capacity index for the best supplementary licence and this latest pricing scheme. This showed that the supplementary licence scheme was far more severe in its restraint effects on central roads than the pricing policy, but that the latter was more severe on a few main roads. However it proved difficult to draw any significant conclusions from these figures other than it appeared that the optimum policy was not restraining as much traffic as expected. The optimum charges were thus increased by 50% and a new run made. This proved less satisfactory than the previous one and a more detailed analysis of both these runs was made in conjunction with the supplementary licence schemes.

The initial analysis showed that the optimum pricing runs had far less effect in terms of restraint on trips made into and around the Railway triangle than the supplementary licence scheme, about the same for trips leaving the triangle, and a more severe effect on those trips with both origins and destinations outside the triangle (as one would expect the higher pricing policy run had consistently greater stress costs for all trips than the lower priced run, apart from some trips with neither origin nor destination inside the restraint area, indicating tgat the models were at least consistent with one another). It thus seemed that an improvement in the benefit would result by increasing the tolls inside the restraint area and particularly on inbound trips. The simplest way to do this is by equivalencing each 2-way link toll with the highest one-way value, as the predominant movement in the peak-hour is out of the Railway triangle. Hence there is little change in the charges on outbound trips but a considerable effect on inbound and internal trips.

With these equal charges and a factor of 1.0 on the predicted tolls from TSW39[16], the benefit derived was within 90% of that for the optimum cordon policy and 80% of the supplementary licence total; ie a dramatic improvement (Table 5, Fig 16).

3.6 Outbound cordon charging

In order to analyse fully the effects of the cordon policy, a policy whereby only traffic travelling out of the railway triangle incurred a cordon toll was modelled. The figures are displayed in Table 5 and graphically illustrated in figure (18)[17]. As can be seen the optimum benefit is reached when the toll is about 80D, which, as might have been expected, is double the optimum toll for the basic cordon policy, and the resulting benefit is much the same. We may deduce, therefore, that the cordon policy restrains both inward and outward traffic across the railway triangle to the same extent.

3.7 Extreme levels of parking charge

As the parking restraint policy did not appear to be very severe when restraining trips, it was decided to model parking in the central area only (inside the ring road) but with the very high charge of 200D. The fitures are displayed in table 5. It is immediately obvious that very little can be gained from this type of policy - the benefit is little more than was originally obtained from the basic parking policy, and trips have not been restrained to any greater extent. It is therefore evident that parking cannot be improved as a policy on its own by variations in area or toll.

3.8 Restraint by variation of fuel taxes or resource costs

This series of restraint studies was being carried out in mid 1973, during the fuel problems brought on by the Middle East War. It would be interesting to compare the forecasts made here with the actual outcome. There are all too many practical difficulties in setting up an analytical comparison due to the variations in the "1981" scenario and the actual situation in Coventry: however some of the qualitative results might be more amenable.

In order to assess the implications of raising the resource or tax costs the total cost functions were altered by differing amounts, and the results then evaluated on the basis of the original cost function and the part of this function attributable to fuel and other tax charges. It was assumed that the basic level perceived resource costs accounted for 86% of the operating cost part of the cost function, and taxation the remaining 14%.

The implications of altering tax and resource costs are closely similar to those of different levels of perceived cost which are fully described elsewhere[12]. The basic algebra is repeated here to clarify the significance of such variations in the present context.

Let the operating costs felt by the user be the function, ϕ, q be 'flow' present (ie base) level and q* be 'flow' at new (ie restrained) level.

Then $\phi_{perceived} = \phi_{actual} - \phi_{tax}$

The community benefit due to toll (tax or perceived cost increase)

$$= (\phi_{TAX})^{q*} - (\phi_{TAX})^{q}$$

$$+ \; - (\phi_{ACTUAL})^{q*} + (\phi_{ACTUAL})^{q}$$

$$+ \; (\phi_{pc} + \phi_{TAX})^{q} - (\phi_{pc} - \phi_{TAX})^{q*}$$

$$= (\phi_{pc} - \phi_{ACTUAL})^{q*} - (-\phi_{ACT} + \phi_{pc})^{q}$$

$$= (\phi_{TAX})^{q} - (\phi_{TAX})^{q*}$$

Two approaches to tax variation policy were considered: (i) tax is constant, so that $\phi^*_{tax} = \phi_{tax}$ and (ii) $\frac{\phi_{tax}}{\phi_{act}} = \frac{\phi^*_{tax}}{\phi^*_{act}}$. Results of both policies are shown in Figure 18. The difference between these two policies is clearly small, but the effect of both policies on traffic flow is severe in comparison with other fiscal restraint policies. Savings in resource costs were about 33,000 pounds/hr, producing net gains to travellers of about 11,000 pounds. The precise figures are displayed in table (6), which shows that increases in fuel costs have a substantial effect on traffic compared to those of traffic restraint, although these effects are spread across the whole network and the 'toll' is not restricted simply to the railway triangle. Analysis of trips entering and leaving the railway triangle zones shows that all trips have been reduced by 16% over the base position by the 2x net costs scheme. The full comparisons are shown in Table 6 and it is evident that in the railway triangle doubling resource or net costs produces results which compare favourably with other fiscal policies, and are of special note when referred to the area road pricing policy.

3.9 Mixed policy strategies

The policies examined in previous sections have been treated separately in order to differentiate between the effects of different restraint instruments. Realistic appraisal of different restraint measures must always be considered in the context of existing means of restraint. Parking controls are the most common form of traffic restraint, and the level of charging could be raised to complement any other form of restraint that might be added.

Figure 19 shows a joint variation of supplementary licensing charges and parking charges. The diagram shows that the joint use of two such restraint instruments can produce a far greater degree of stability than either on its own.

The effect of a supplementary licence is to place a heavy degree of restraint on trips entirely within the restraint area: this means that an effective floor has been set under any parking charge that might be used to complement it.

Cordon charges are more flexible in this respect, and the diagram in Figure 20 shows how this can be exploited. The section through cordon charge 40d is shown in Figure 21. The zero has been suppressed in this diagram in order to show how the small variations due to network peculiarities show up. The optimum optimorum is at 60d parking and 40d cordon: it is clearly a significant shift from the optimum at a zero parking charge, but the variations between 60d - 120d are less important.

It was not feasible in this study to examine all the different types of traffic restraint in simultaneous variation: nor to include the effects of private parking spaces or poor enforcement; nor to examine the differential revenues and returns between various income groups. The enormous number of such simultaneous adjustments of concurrent issues and instruments is only likely to be worth the considerable effort when a highly realistic scenario is under discussion, and area traffic control devices included. This study was aimed at developing tolls, and demonstrating the relative importance or relevance of different possible restraint instruments in a set of reasonably recognisable scenarios.

3.10 Summary economics and physical effects

The complexity of the traffic effects makes a selective presentation of results essential. The railway triangle has been the focus of the restraint schemes, and figures 22 and 23 show how the traffic flows and travel speeds vary in this vicinity from restraint to restraint. The average speeds were calculated for three groups of links: (1) all those inside the inner ring road (2) all those in the remainder of the triangle and (3) those links just outside the triangle. The greatest increases in speed inside and outside the triangle were produced by supplementary licensing, but area road pricing was effective in raising speeds only within the triangle. Figure 23 is an illustration of the changes in total flow in and out of the triangle, and of the total number of trips to and from the triangle area. Supplementary licencing produces considerable reductions in both flows and journeys, reflecting its severity in local impact. Parking charges have little impact on the traffic moving across the boundaries, and evidently reach their (limited) effect by sharp reductions in journeys made to or from the area. Cordon road pricing has a less

severe effect on journeys than any other policy, yet has a broad effect on flows across the triangle boundaries, and achieves high benefits. The area road pricing results in Figs 22, 23 are those based on charges restricted to the railway triangle, and produce neither the best benefits nor the greatest reductions in traffic flow. These two diagrams demonstrate that the different restraint instruments affect traffic flow and travel demand differently.

4. PATTERNS OF DEMAND AND TRAVEL UNDER RESTRAINT

4.1 Desire line density maps and trip length distributions

Desire line mapping[17] is a technique for displaying travel movements and trip length distributions. The scenarios set up during this study were plotted on a single diagram together with an intermediate scenario (produced during the Coventry TSG Study). Figure 24 shows how the density trip movements shifted between the three "years" "1967", "1976", "1981". The substantial increases in trip density between 1967 and 1981 are evident, as is the altered emphasis of this demand.

The same techniques were then applied to the differences between the basic trip matrix and each of the trip matrices produced for each traffic restraint policy. Figure 25 shows the pattern of the effects and the varying degrees of intensity of impact.

The journeys in each direction across the network can also be analysed by this means.

Trips can be classified into three types, through trips which have their origin and destination outside the restraint area, internal trips which have both their origin and destination inside the area and access trips which have either their origin or destination outside the area. When the cordon restraint is imposed all through trips are charged twice whereas access journeys are only charged once and internal trips not at all. The parking charge differs as all internal trips are charged twice, access journeys once and through trips are exempt. Supplementary licensing naturally charges each type at the same rate. Figure 26 displays a directional analysis of trip lengths within which some of the geographical factors can be expressed.

Short trips were generally affected more than long trips under all restraint measures. For trip lengths of 6 to 8 kms no restraint had any great effect; from 10-12 kms all policies produced a reduction, although including the M6 and A46 were not so strongly affected, and are dominated by movements which never actually enter the city.

In both directions along the A46 the cordon restraint caused an increase in the number of trips of length 0.5-1 km but only an increase in those in the north easterly direction with length less than one kilometre. Parking restraint also caused an increase in the 4 - 10 kms trips in both directions and in the north-easterly direction of the 12 - 20 kms range but otherwise an overall decrease. All three policies caused the greatest reduction in very short trips of less than 0.5 kms with a significant decrease in trips of 2-3 kms and some effect on longer journeys of 10-12 kms. Parking restraint has very little effect on the long trips of 10-20 kms as these are probably journeys across the railway triangle, or through trips, which are unaffected by the charge.

The most strongly affected movement is in the direction of the primary route typified by the A444. Supplementary licencing halved the trips below 0.5 kms caused the greatest reductions for all trips in each direction. North bound traffic of less than 14 kms was reduced by all restraint policies and at this distance parking restraint caused a slight increase of one per cent. On the other hand all south-bound movements other than those for cordon restraint increased for trips in the range 0.5-2 kms. These rose by over four per cent. The A444 carries a larger percentage of heavy traffic than the A46. Much of the movement southwards starts in the railway triangle, and a major part of the north bound traffic travels across the area, watching the greater percentage reduction in north bound traffic of 10-12 kms in length.

The M6/A45 route follows the same general pattern as the other primary routes. The most significant decrease caused by parking control was in the o.5-1 km range. This was also true for supplementary licencing in the north westerly direction, where there were more 4-10 km trips. Cordon restraint produced 6% increase in the opposite direction for trips of 0.5-3 kms with a general decrease elsewhere. The major difference between this route and the other two is that there was very little effect on trips of length more than 6 kms by all three restraints, due to the high percentage of long distance traffic by-passing the city centre.

4.2 Accessibility and trip making shifts

The geographical distribution of the effects of restraint is of intrinsic interest, and the match with the distribution of people provides some basis for appraising the pattern of impacts and benefits produced by each different policy. The starting point could be either a population distribution or an index of the characteristcs of each area. The resident population would be a good descriptor for the effect of movement when the people are actually there: as this is clearly inappropriate for many purposes, a second type of specification would be worthwhile, characterising the land uses in some detail.

The 1971 Census provides information on a ward basis which can be described as social indicators. That is they can be used to differentiate social groups within the community. Coventry City planning department adopted 22 of these indicators to describe the pattern of distribution in the town. There are two types of social indicator, one type describes population characteristics and the other the household characteristics. The choice of indicators is conditioned by the available information, and any selection must be arbitrary: however the indicators used were as follows.

Population

1. Residents with both parents from the new Commonwealth
2. age group 0-4
3. age group 5-14
4. age group 60-65
5. Married female activity rate
6. Unemployment (workers seeking work and sick)

Householders

7. households with no car
8. vacant dwellings
9. dwellings with no hot water
10. households sharing or lacking hot water
11. dwellings with no bath
12. households sharing or lacking a bath
13. dwellings with no inside WC
14. households sharing or lacking a WC
15. households sharing dwellings
16. households at 1.5+ persons per room
17. households at 1-1.5 persons per room
18. single parent households with children under 5
19. households in privately furnished dwellings
20. households with 6+ members
21. one-person pensioner households
22. two person two pensioner households

In addition to these the 1966 Census provides information on

1. socio-economic groups 11 (unskilled)
2. socio-economic groups 7,10,15 (aemi-skilled + service)
3. social class V
4. social class IV

All of these indicators were ranked and the top five given points of 1 to 5. The sum of these points then gives the score taken for each of the 18 wards of Coventry.

Figure 27 is a map prepared by B G Taylor of the Planning Directorate at DOE, which shows the distribution and weight of the aggregated social indicators.

The map combines population and other variables effectively: the lower the score, the greater the social advantage. The central wards of Coventry coincide with the railway triangle, and are clearly poorly advantaged. The pattern of travel demand changes and the pattern of averaged generalised cost changes are shown in Figures 28 and 29. The generalised cost changes are based on averages from origins, and consequently correspond more closely to employment than to resident population.

The general picture presented by Figures 27, 28 and 29 is one of considerable variety: the detailed patterns of travel and cost changes are substantially different for each policy. This emphasises the increasing need to assess shift or transfer effects in addition to aggregated results of economic measures, as these shifts can be of the same or greater magnitude than the net consequences. As a practical example, there is little to choose between supplementary licencing and cordon charging on net benefit grounds: the enforcement and installation costs might well give cordon changes a distinct edge, and the increased flexibility of the cordon system might be considered to be desirable in its own right. The substantial differences in pattern of impact between the two systems raises another equally important question, the choice between one pattern of impacts and another. By matching Figures 28 and 29 to Figure 27 it becomes evident that a poorly advantaged area would suffer heavy restraint under supplementary licencing. This is not a simple result to interpret. If the resident did not own cars (likely, in this area), then the sharp traffic reductions would be a key benefit, but if all the employment in the area was unsuitable for the residents, they would be suffering a sharp reduction in their accessibility to their jobs. Further questions then arise on the degree of balance between residents and jobs in the area, and the average length of journey to work.

It is inescapable that as a result of this study of the first order economic effects of traffic restraint, the questions of geographical distribution and income group differential impacts will arise, as both perspective and figures are now available (at least in an order of magnitude sense) for the uncertainties in the policy studies to reach this more practical stage and change of emphasis. As an increasing number of interrelated issues are linked to economic policies, and a numerate perspective achieved of all in concert, then the closer distributional decisions become. The environmental consequences of traffic restraint have also been

linked within this study and are treated as a separate section to follow.

The detailed results of matching figures 27, 28 and 29 provide several illustrations of these distributional questions.

Supplementary and parking policies produce a very wide range of effects, and consequently pose numerous awkward distributional questions. In both cases the railway triangle is the most hit and it is interesting to note that this is the area least socially advantaged (Figure 27). It might therefore be argued that the triangle restraint area is too large as it extends into areas beyond the control business district of Coverntry.

The cost differences for the cordon policy show the lowest costs of the four policies in the railway triangle and even lower costs under restraint in the central area than in the base. This is a result of greater freedom of movement for trips solely within the triangle, which therefore escape charging at the cordon.

The parking costs show cost reductions for a very large primary residential area to the north and west of the triangle: as a direct consequence the number of trips rise (Figure 28) in this. This has implications not only for land uses but also for the public transport system which would suffer reciprocal decline in passengers.

The pricing point system (flat rate) gives the best overall distribution of cost differences and may be said to be the most equitable, as would be expected from the simplest economic analysis but need not have been borne out by the detailed simulations for these scenarios.

We can deduce from Figures 27, 28 and 29 that:-

(1) Supplementary licencing produces the least progressive effect by placing the greatest accessibility shift in the 3 central wards (ie the triangle), and the least on the peripheral areas to the north, east and west.

(2) Parking changes produce the same general patterns as supplementary licencing but the range of accessibility shifts is not so large, and in some areas, actually induce traffic.

(3) Point pricing produces a more random distribution of accessibility shifts but still has the strongest effect in the less advantaged areas, and the least elsewhere.

(4) Cordon charging actually produces progressive effects, and might therefore be rated more highly as a result. The less advantaged areas retain their mobility and are affected least, while the outer areas suffer the revenue.

Although it would be necessary to adopt a different form of analysis to to further the general social distributional impacts are clearly highlighted by this analysis, and for future practical studies some conclusions may be drawn.

(a) The area chosen for restraint will affect the pattern of accessibility shifts, and could possibly cause regressive redistribution if not carefully chosen. In such cases restraint revenue would be earmarked to remove such redistributive impacts.

(b) Only one policy (Cordon pricing) produced progressive redistribution affects, all the others would require revenue earmarking to avoid regressive impacts. Further attention should therefore be paid to cordon schemes for their potentially progressive operation.

5. ENVIRONMENTAL IMPACT FORECASTING AND APPRAISAL

When transportation models were originally developed they were intended to assess the benefit to the road user of suggested schemes of road construction, and the consequent advantages to the community. The assessment concentrated on the improved travel opportunities, and later came to analyse the distribution of these benefits within the community. Only recently, however, with the increasing public concern over the quality of the environment, has account been taken of the effect that road traffic passing through an area has on the local population. As described elsewhere,[16,18] the PANIC model was developed to provide this level of analysis within the RRLTAP model, and this report describes the methods developed for analysing the environmental impact of a set of traffic flows, and the changes to be expected when that set of flows is altered. Examples are taken from a study of the implications of fiscal traffic restraint measures, but it is intended to give a general survey of the methods used in context rather than a technical summary of the study.

The most noticeable effect of traffic on the local population is the noise generated by passing vehicles, but there is a wide range of intangible ways in which local residents are affected by traffic, such as visual intrusion. The modelling of such intangible quantities would be very difficult and in PANIC attention is confined to the noise and atmospheric pollution caused by road vehicles, and to the delay to those wising to cross the road. The atmospheric pollution consists of a variety of individual pollutants which are modelled separately. The systems analysis and review which produced PANIC[18] contained a range of empirical equations collected from the

literature. In preparation for the study of traffic restraint, using the City of Coventry as an example, a small scale environmental survey was carried out in four areas of Coventry and from this survey a new set of empirical equations was obtained for calculating levels of noise and atmospheric pollution. The results reported here use equations largely from this latter source,[3] although some of the original equations were retained for purposes of comparison with other work.

In the preliminary tests many interesting points arose concerning the use of empirical equations in a transportation model, and particular difficulties stem from the application to a congested model of equations that were necessarily derived from survey data containing no comparable flows. For a variety of reasons these difficulties arise especially in the analysis of atmospheric pollution, and the equations predicting noise levels are far more satisfactory.

These equations, when applied to the set of flows output by a transportation model, lead to a mass of noise levels and pollutant concerntrations and these must be assembled to give a useful summary. The objective of this study was to develop techniques in application for the comparison of alternative policies in as broad an economic, social and environmental context as possible. The differences in level following from a change in traffic, resulting from a change in traffic policy were calculated. Before applying the summary process, knowledge of the population distribution led to the calculation of the mean reduction in noise level, but because of the poor agreement between the concentrations of each gas by different equations this approach had to be modified for atmospheric pollution. Instead of relying on the predicted change for each street, this is expressed as a percentage of the original concentration and used to give the mean reduction as a percentage of the original exposure.

These techniques are refined by performing the calculations separately for different groups, each group consisting of those whose original level of exposure lay in a predetermined band. The manner in which the changes predicted vary with the original level of pollution is investigated, and it is seen that the effects at different levels vary considerably. The reductions in noise levels are generally very small, and it is difficult to discriminate between policies. Most of the policies produce genuine reductions in atmospheric pollution, but in view of the considerable effects of the policies in reducing the number of journeys by raising travel costs in parts of the network these reductions are surprisingly small.

A subsidiary reason for performing the analysis at different levels is the idea that changes of equal magnitude at different levels may not be comparable; if this is the case then the effect will be less noticeable over the small bands of

exposure used. The whole question of the human perception of, and response to, pollution is being actively studied, and when definite conclusions emerge the results presented here could be the basis of a technique for the prediction of the response of the population to the simulated changes; until such time an analysis such as the one included can only be descriptive.

A final section describes the use of the simple pedestrian activity model included in PANIC, which calculates the mean delay experienced by those wishing to cross the road and predicts the numbers of pedestrians on the pavements; this is then used to compare the exposure to pollution of pedestrians and residents. This application is largely illustrative, owing to the admittedly small range of the equations and the lack of comparable equations from other sources. It is essential that further work be undertaken to estimate the exposure profiles and numbers for different types of affected areas and people.

The methods used here for the analysis of environmental impact have been developed for use in a particular role, but are sufficiently robust and flexible for use in any situation where a transportation model would be required. The highly congested traffic assignments of the "1981" Coventry scenario on which PANIC operated for this report offer the most stringent tests, and it is encouraging that the results provide a coherent and useful perspective under these testing conditions.

5.1 The Environmental Impact Model

Transport models differ in the degree of detail included in their output; the simplest consist of the simulated flows on the model network, but more sophisticated models offer greater detail. The Dynamic Highway Transportation Model[19] for example concentrates on the effect of junction configurations and outputs average vehicle delays and maximum queue lengths at each junction, from which steady cruising speeds, number of stops per hour and the time spent stopped or idling may be inferred. In view of this range of detail, the environmental impact model should be designed to make best use of the facilities of the transportation model with which it will work. The usefulness of the extra detail will be seen later, but as the RRLTAP model[16] (within which the PANIC model operates) outputs link-by-link flows, PANIC is designed to operate with this basic input; the model must consequently estimate on the basis of a traffic assignment the levels of various environmental impacts caused by the traffic, and then summarise this mass of data in a comprehensible manner.

Road vehicles driving along a street affect those living in that street in many ways. The most noticeable and intrusive effect is noise; there is also the

emission of a variety of atmospheric pollutants, the danger of road accidents and a range of other effects that are less easily quantified, such as visual intrustion. The acronym PANIC stands for Pollution Pedestrian and Noise Impact Computation and indicates the environmental aspects that are studied. Pedestrians enter the analysis at two points; the delay to pedestrians wishing to cross the road depends on traffic flow and may be studied, also the exposure to pollution of the pedestrians may be calculated. The available information on pedestrian movements is limited and relates largely to shoppers, consequently the impact on shoppers will be studied rather than the other parts of the pedestrian "population" whose numbers are less well predicted.

Once the range of impacts to be considered has been established, the indices to be used are easlily agreed. The air pollution caused by road vehicles is largely the result of exhaust gases, although there is also a contribution from the evaporation from fuel thank and carburettor. The exhaust gases contain the following pollutants, which amount to approximately 3% of the mass in the air

Carbon monoxide
Oxides of nitrogen (NO, NO_2)
Hydrocarbons (unburnt petrol and organic compounds produced from the petrol)
Lead compounds
Smoke

The concentrations of these pollutants in units either of p.p.m. (parts per million) or $gm.m^{-3}$ (microgrammes per cubic metre) will be the basis of the analysis of these emissions.

In calculating the noise levels generated by passing road vehicles there are a range of indices available; the index selected for use in this report is the L_{10} index, whose value during a period of time is that level in A-weighted decibels exceeded for 10% of a specified period, normally 18 hours. In fact the relevant module of the PANIC suite is designed to accept a considerable range of estimation equations that may be expressed in a given format, so that any other noise index could be used.

In the basic specification of the PANIC model[18] system a range of possible uses and extensions of the fundamental model are discussed; the results given here are limited to a descriptive form. Consequently distributions of the various environmental impacts through the population are given and no attempt is made either to estimate people's reactions to a particular situation or to deduce from weighted combinations of comparable distributions of the several pollutants a composite

measure of pollution. No feedback to the traffic assignment is allowed to occur from the predicted pollution levels, and any question of adjusting the assignments to satisfy exogenously defined pollution standards has been excluded from this study of restraint measures at this stage.

Various criteria could be applied for weighting change according to the level of exposure; for instance, a man exposed to a 60dB noise level will react differently to a 1dBA change than a man exposed to 80dBA. Thus, if a part of the population experiences an increase in noise and the remainder a decrease it may be difficult to decide whether the change is beneficial. The addition of 1dBA to 50dBA or to 80dBA also produces rather different results. Consequently the mean changes in exposure to pollution are calculated, rather than to weight the calculation according to a theory describing people's responses to change and level variations. Work is in progress to discover the financial compensation that people require for tolerating various levels of pollution concentrations and when results have been obtained it may be possible to extend PANIC.

The system for modelling environmental impact described here should be regarded as one of the tools to be used in presenting the consequences of transport alternatives; any attempt to assimilate this part of the analysis into the general economic analysis by some system of pollution costing would pre-empt the judgement of the decision-maker. Thus, even if a system for costing pollution were to be agreed, the methods of presentation developed here would still be needed as environmental impact has a place in the analysis of far greater significance than a series of entries in a set of accounts: it is, however, necessary to put relative numbers on environmental factors to allow a fair appreciation of the scale of any such effects in comparison with other impacts.

Considerable importance is attached to the interpretation of the basic pollution predictions using knowledge of the population distribution, for it is the impact of road traffic on those largely ignored in transportation studies, the local population, that is the main concern. It would be clearly advantageous for the population if a large part of the traffic in populous areas were diverted onto unpopulated roads: the total pollution production may not decrease, but the explosure of the residents will be reduced and it is necessary to identify this.

The population is not static, and particularly during the working day its distribution will vary considerably from the distribution of the residential population: nonetheless, it is the predicted residential population that will be used here. Another refinement would be to model the precise exposure of this population by allowing for the shielding effect of the houses, but this would require

comprehensive data concerning constructional standards. Moreover, it is the consequences of traffic policies that are the main concern rather than the attempts of local authorities and residents to mitigate the nuisance caused by traffic, consequently road-side pollution levels are modelled rather than the levels to be expected inside houses adjacent to the road. This level of representation is compatible with the analytical framework of traffic restraint and transportation modelling, which must be at an aggregated level in order to assess area wide strategies over a wide region.

One major difficulty in analysing the environmental implications of the results of a transportation model lies in its limited scope. In order to be economic to use, the roads represented in the model must usually be limited to a proportion, albeit the busiest, of the city's streets: the scenarios of Coventry include only a fifth of the city's streets but in "1967" these streets carried all but one twentieth of the traffic. The streets excluded have the majority of the population, but are less amenable to traffic restraint policies and being lightly trafficked, will be only lightly polluted. It should be appreciated that references to "weighting by population" or "exposure of the population" do not include the complete population but only that part that lives by the streets which have been included in the scenario.

5.2 The estimation of levels of pollution

The general philosophy of the system has been discussed, and now the first state in the impact analysis will be specified, where the levels of pollution on the individual streets are to be predicted.

The degree of detail and accuracy in the predicted levels of pollution is related to the complexity of the model used, and the problem is most clearly seen in the case of atmospheric pollution. The concentration of, for example, carbon monoxide depends on many factors in addition to traffic; the gas is emitted by many other sources and the gas in a volume of air at a particular point will contain a proportion generated by vehicles on other roads. Moreover, the manner in which these contributions combine and disperse is governed by the prevailing atmospheric conditions. Thus any equation which attempts to predict the concentration of an airborne pollutant can have only limited success, and in order to improve on this a dispersion model is needed to predict how pollutants from many sources combine and disperse. Such a process was used for the Stanford Research Institute where the output from the Dynamic Highway Traffic Model was used by the Moon emission model to calculate the quantities of carbon monoxide generated; these generation predictions

are then used by the APRAC-1A diffusion model to produce predicted CO concentrations at a series of points. This work required details of the meteorological condition over the city at the time, which could never be possible in broad strategy assessments for the future.

This method has been used with success,[20] but was quite inappropriate to the designing of PANIC. A simpler approach would be more relevant, relying on empirical equations for concentration prediction and not requiring meteorological details which cannot generally be predicted for the future in sufficient detail. This reason was the prime objective of PANIC, which is to systematically compare the environmental consequences of alternative transportation schemes. The use of a meteorological model of dispersion over time would enhance the accuracy of predicted concentrations, but because of the differential process applied to the results much of this extra accuracy would not be needed, and the incompatability of a continuous time model of diffusion and a steady state averaged mean forecast expectation in transportation analysis was quite unacceptable. A methodology can be developed to present changes in exposure to pollution with sufficient consistency to give a firm basis for analysis. There are certainly some applications of an environmental model that call for the extra power of a dispersion model, particularly if there is an attempt to discover if externally defined environmental criteria are satisfied for immediate implementation or to assess the efficiency of proposed control mechanisms, and the time scales of phenomenon and policy would then be in balance.

The accuracy of the pollution concentration predictions would be enhanced by knowledge of the lengths of time vehicles were spending in the different phases of the driving cycle,[21] ie accelerating, cruising, decelerating and idling. The rates of emission vary considerably with the phase, and some transportation models do provide this information. These times could have been simulated from the RRLTAP output, but this was not done since empirical exhause emission gas concentration equations including these variables have not been the object of any research to date; consequently no data was available on which to set up empirical forecasting equations.

The situation is not as complex for noise. Unless a street is only lightly trafficked the dominant source of noise is the passing traffic. Noise is instantaneously dissipated and minimally dependent on the climate, at least over the short distances of interest here. The effect of noise generated in one street on adjacent streets can be modelled, and also the reflection of noise by house fronts, but the effect is slight and will not vary between simulations.

Once the criteria and techniques to be used in predicting noise levels and pollution concentrations have been selected the design of the estimation section of the model is straightforward. Since heavy vehicles are quite distinct from lighter traffic in terms of pollution emission, private and goods traffic are modelled separately. The definition of "goods" vehicles is not sensitive, and the specification of "Over 30 cwt GULVW" is adequate at present. Attempts to split the categories of goods vehicles have not yet reached an adequate degree of reliability for use here.

The equations used here come generally from the special Coventry Survey[3] but some have been retained from the literature review[26] for purposes of comparison. The considerable difference in the two sets of equations certainly indicates the usefulness of carrying out such a small-scale survey when an environmental analysis is performed: all equations referred to in this report are included in Table 8.

The results of initial work on PANIC[21] substantiated the degree of concordance to be expected from L_{10} equations in contrast to atmospheric pollutant equations. Despite considerable variations in equation form differences in the L_{10} results could largely be accounted for by the differing implicit statements concerning the background noise integrated within the various equations. Variations between predicted pollutant concentrations could not be reconciled with any degree of precision.

Background noise level variations can be important, since the analysis of the data from six Coventry sites[3] showed that the most satisfactory equation that could be obtained by linear regression techniques contained a separate background level for each site, ranging from 51.3 dB to 54.1 dB. These variations depend on local geography both for noise propagation effects and the nature of the traffic flow. Vehicles ascending a hill will driver in a lower gear than on the level so that for the same traffic volume one would expect the noise levels at the hill site to be uniformly higher than at the level site. To the extent that topography varies in most cities these effects will be smaller than the uncertainties inherent in the empirical equations.

This is equally true, but less important, for the pollution equations, since only a part of the variance in their predictions is related to different background levels. Later a means of expressing the forecasts that interpret the predicted change in level in a reliable way will be specified.

These pollution prediction equations will be more reliable for lower flows than for high, since the data used to derive the equations were gathered in or before 1973

and do not generally include very high flows. In the Coventry survey mentioned previously two-way flows rarely exceede 1800 vehs per hr, whereas in the "1981" scenarios many streets had higher flows. Consequently, equation terms fitted by the regression procedure to provide slight improvements in fit for low flows assume an unreal importance for high flows, and distort the predictions. An extreme example of this behaviour is given here from the Coventry survey;[3] the quadratic equation obtained by linear regression to predict the concentration of nitrogen oxides was:

$$\text{Concentration} = 0.037 + 0.00026Q - 0.0000001Q^2 \text{ ppm}$$

where Q is the two-way flow in vehicles per hour.

The standard error of the coefficient of Q^2 was found to be 0.0000001 so that this term cannot be considered reliable; nonetheless, for large Q it becomes important so that if Q>1300 then increased traffic leads to reduced concentration, and negative concentrations for flows above 2650. This is another example of the difficulty of forecasting on the basis of observations made in the less congested conditions of the past and perhaps it is indicative that the equations obtained in Coventry in 1973 lead to lower estimates than earlier equations.

These forecasting limitations apply also to noise equations, but owing to the logarithmic functions required in these equations the effect is much less: a doubling of traffic flow leads to an increase of only 2-3 dB in the L_{10} index.

The lack of a queuing mechanism in transportation models at a strategic scale meant that the limitations imposed on PANIC are too severe for air pollution forecasting. The capacity of a street may be defined to be the greatest possible flow of vehicles along the street. When this flow exceeds the capacity the streets become congested, and a queue will form. The use of RRLTAP mechanisms to limit flows to the street's capacity leaves uncertainties in the degree of queuing that might then occur. Excessive flows may thus be present in the input to PANIC, which will give rise to high concentration predictions which may be unrealistic. Queuing effects would produce even higher levels than any movement velocity could give rise to, these high concentrations may therefore be dealt with acceptably by the models as now used.

5.3 Analytical techniques

Summaries of the mass of individual link results are of great importance and are basic to the practical utility of any environmental impact model: the methods used here were reached through a series of trials.

The networks and populations for the two basic (unrestrained 1967, 1981) scenarios in Coventry are different, and so it is not possible to carry out a direct evaluation

of the changes that occur between the two base years. Summaries of the distributions of the several pollutants can be compared. Cumulative plots of the exposure to each level of pollutant by each group of the population have been used previously by the Coventry Study Team.[2] The L_{10} forecasts made by this group for the (rather differenct) scenarios appropriate to the CTS assessments are shown in Figure 30.

Such exposure graphs plot for each level of pollution L_x the percentage of the population exposed to a level of at least L_x.

The comparison of the exposure to pollution in 1967 and 1981 by the shift method is inappropriate because of the great differences in concentration of the different pollutants, and instead the "proportional shift" method is used: if to ordinate n% correspond abcissae 1_{1967} and $_{1981}$ for the respective exposure curves then the proportional shift at n is $p(n) = \frac{1_{1981}}{1_{1967}}$. A complete discussion of the application of various equations to the base scenarios is given by reference 22, and only the differential results for traffic restraint will be given, referred to a "1981" unrestrained situation. This will minimise variations, but the clarity of the shift effects will be maximised.

5.4 Noise level exposure shifts

The methods of comparison that may be used when the networks or populations differ have been described in the previous section, but the majority of the work in the restraint study was concerned with the analysis of the effects of altered traffic assignments caused by the imposition of restraint policies. For this work a common network and population were used, and more comprehensive methods were developed. It must be stressed that the form of exposition chosen will show the differential effect in a target year but not the changes from one realisable position to another. To do this, a "1967" to "1981" differential would be essential, but would mask the differing characteristics in the target year alone.

These methods centred on the difference in predicted levels on each link. Suppose that under policy A the level of a given pollutant calculated for link n is 1_n^A and under policy B is 1_n^B. The reduction for n brought about by the policy change is

$$r_n = 1_n^A - 1_n^B$$

so that if r_n is positive a genuine reduction has occurred and if r_n is negative an increased level of pollution has resulted. Generally A would be the "do-nothing"

policy, so that r_n would be the reduction brought about by the introduction of policy B. If the population of the streets included in the model is known it becomes possible to discover the distribution of change through the population by dividing the range of possible reductions, both positive and negative, into a number of segments and then calculating the number of people whose reduction falls within each segment. A development of this technique is to perform this distribution in several stages according to the original level of exposure, and an example of this is seen in Table 9, where the effects of two different restraint policies are compared. This refinement is introduced to investigate the distributional aspects of the changes: it is of interest to see whether the benefits of the change are experienced by those most affected by the pollution. In Table 9 two policies with differing distributional characteristics are compared. The L_{10} levels chosen for analysing the original exposure were chosen as the kind that might be mentioned in legislation, and the population in each noise range for the unrestrained model is:-

Range (dB)	Percentage of population in range
≤70	2.41
70 - 75	6.33
75 - 77.5	48.74
77.5 - 80	36.77
> 80	5.75

The ranges of original pollution levels by which the analysis is carried out will be referred to as $P_1, P_2 \ldots P_r$, so that here P_2 is the range 70 - 75 dB and P_5 is the range >80 dB.

The choice of two policies for presentation in Table 9 was arbitrary, as such distributions can be produced for each policy. The difficulty in comparing the effectiveness of two policies using these distributions is evident., particularly since the bulk of the population experience very little change. Indeed, in the process of grouping changes for presentation in the form of Table 1 a degree of accuracy may be lost that could prove to be critical. Suppose that policy A produces a reduction for the complete population of 0.49 dB whereas for policy B one tenth enjoys a reduction of 0.51 dB and the remainder an increase of 0.49 dB. When expressed in the form of Table 1 it would appear that B is more effective than A, whereas it is more reasonable to regard A as more effective. An instance of this

occurs in the results for fuel taxation: it will subsequently be seen that for all groups except those with exposure between 70 and 75 dB, this policy produces reduced noise levels, but this is not clear from Table 9. The delicacy of this division could be increased by increasing the number of divisions but this leads to increased difficulty of evaluation and the possibility of error remains.

A direct method for approaching this difficulty involves the accumulation of reductions, so that instead of forming a distribution of the reductions they are summed:

$$R = \sum_n r_n \times p_n$$

where p_n is the population on link n. This is the total reduction and the mean reduction (per person) is

$$\bar{R} = \frac{R}{\sum_n p_n}$$

The division according to original exposure introduced above may be used, so that if N_t is the set of links for which the original level lay in range P_t,

$$R(t) = \sum_{n \epsilon N_t} r_n \times p_n$$

and $$\bar{R}(t) = \frac{R(t)}{\sum_{n \epsilon N_t} p_n}$$

It may well be that a given change occurring at different levels of pollution has a different significance, and that a system for weighting changes should be incorporated. This may easily be done in the system developed here, but in the absence of firm evidence unweighted changes have been used in this work. A point of great importance is the reference basis to which these shifts are referred. There are three different bases, each of which have their own merits and demerits,

(i) assesses shifts between 1981 (no restraint) and 1981 (restraint)
(ii) assesses shifts between 1967 (no restraint) and 1981 (restraint)
(iii) assesses shifts between 1967 (restraint) and 1981 (restraint).

The mean reductions corresponding to the distributions of Table 9 are given in Table 10 on the basis of option (i). For many purposes the shift from now (1967, no

restraint) to the new future state (1981, +restraint) is more useful, and the shift between 1967 and 1981 with the same policy in effect in both areas provides yet another set of answers to further pertinent equations.

Original Exposure	Mean reduction resulting from: Fuel Taxation	Supplementary License
≤70 dB	0.843	1.148
70-75 dB	-1.215	-0.234
75-77.5 dB	0.022	0.078
77.5-80 dB	0.169	0.056
>80 dB	0.278	0.081
All	0.032	0.004

This comparison shows the varying effect of the policies on different groups of the population. The mean reduction for the complete population is also calculated, but it undoubtedly disguises significant distributional effects.

The small size of these mean reductions may result from a near-cancellation of increaases and decreases, or it may be that only small changes have occurred (as of course would be expected for such mild policies at traffic restraint calls out). The distributions of Table 9 suggest that the former is the case, and as a counterpart to the reduction the total change is defined:

$$C = \sum |r_n| \times p_n$$

(if $r_n \geq 0, |r_n| = r_n$ and if $r_n \leq 0$ $|r_n| = -r_n$)

This leads to the mean change (per person) experienced by those whose original level of pollution lay in range P_t,

$$C(t) = \frac{\sum_{n \in N_t} |r_n| \times p_n}{\sum_{n \in N_t} p_n}$$

Thus there is a differentiation between the concepts of "change" and "reduction"; the latter is an analytical quantity designed to discover whether there has been an overall improvement resulting from a different distribution of traffic, whereas the former is a descriptive quantity to measure how much alteration has occurred. The changes that correspond to the reductions presented above are:

Original Exposure	Mean Change resulting from: Fuel Taxation	Supplementary License
<70 dB	1.941	1.272
70 - 75 dB	1.241	0.903
75 - 77.5 dB	0.324	0.320
77.5 - 80 dB	0.197	0.225
>80 dB	0.278	0.115
All	0.372	0.335

As the least change that the average person could recognise is approximately 1 dB, this shows that only a small part of the population would appreciate that a change in noise levels had occurred, if the 1981 (unrestrained) situation had been that which obtained before the application of restraint. At this point it becomes essential to be explicit about the reference base; if any variant of 1967 situations were used, then the shifts would be more of the order of (3)+0 to (3) +3 dBA. These changes then become significant in subjective terms.

The noise results for the six systems of traffic restraint studied are presented in Table 10. The charges associated with each system are at such a level as to give optimal economic performance of the transport system, but no description of the systems or the methods used to model them are included as the objective is to demonstrate how a series of policies may be compared rather than study the environmental consequences of traffic restraint measures.

The populations of the five groups are of different sizes, and in order to discount this, results have been expressed in "per person" terms. The different sizes must still be indicated to avoid any bias towards policies that favour small sections of the population. To achieve this the total reductions and total changes are plotted in Figs 31 and 32 for the various ranges of exposure.

Ranking of the restraint policies would require criteria to be specified in these terms, but certain general conclusions may be drawn. The choice of reference base is also critically important here. The main conclusion concerns the small differential effect on the noise exposure of the policies. Although up to one tenth of the private trips included in the unrestrained model are "priced-off" when the imposition of a restraint policy raises the cost of the trips above the value that the traveller places upon them, only a fraction of the population would recognize that a change had occurred, and even fewer benefit significantly. The reason for this lies in the assumption that goods traffic will not be affected by restraint policies, for maintaining the noisier traffic constant will certainly reduce the

effect of reductions in the quieter traffic. Another factor is that most of the policies act directly in the centre of the city and so tend to deflect some traffic into the suburban residential areas. If however the 1967 base were to be used (as would be entirely reasonable here), then the small differential changes will all lie in a fully perceived region of level shifts.

This illustrates the need for sensitivity in an environmental impact model: considerable changes in the traffic distribution may only lead to small changes in the noise distribution and great care is needed to preserve accuracy.

A direct application of the PANIC outputs described here is to calculate the number of people who might in the future become entitled to compensation due to increased noise under the Land Compensation Act (1973). This permits payment for an increase of at least 1 dB at levels above 68 dB in the 18 hour L_{10} index; it is one of the few environmental costs yet available and the total payment may be evaluated from the distribution of reductions when the original noise level was at least 68 dB. Unfortunately the Land Compensation Act includes a specification of L_{10} that is to be used for this purpose, and defines an equation which must be applied to give reckonable dBA values. This equation is incompatible with the empirical equations deduced for PANIC and the functional forms required are not presently catered for within the RRLTAP/PANIC system.

As the results here are expressed in terms of a shift from "1981" unrestrained to "1981" restrained, the figures would be of little value, The dBA shifts would need to be obtained in a rather different way to be of use for Land Compensation Act purposes. The base point for reference and for measurement has a critical role to play when national traffic increases are also being handled simultaneously. To give a concrete example: choose an achievable reference base in "1981" (this must be "parking"). Then the difference for Land Compensation Act purposes would be referred to this pattern and level - and logically would only be applied to a joint-optimal parking + "x" policy set.

Considerable care is needed to distinguish between forecasts, variations on simulations of the present, and the implications of empirical forecasting equations and before-and-after, measurement based, specifications of L_{10}.

5.5 Airborne pollution exposure shifts

Concentrations of airborne pollutants are far less easy to predict with any precision; but unlike noise, people cannot readily detect 20 ppm of Carbon Monoxide - although a few ppm of aromatic hydrocarbons are quite a different matter.

These factors lead to a changed emphasis in the methods of analysis used here.

When several equations are available to predict concentrations of a single pollutant there is insufficient evidence to choose one equation as superior to or more representative than, any other.[22] A criterion is necessary which gives comparable results by the use of any of several equations.

The population can be split up according to original exposure so as to give the same groupings for all equations. If from the exposure curve for equation E in the pre-restraint case it is found that 1_t is the concentration suffered by at least t% of the population, for t = 25,50,75. The groups are then E_1, E_2, E_3, E_4 where E_n consists of all those exposed to concentrations between 1_{25n} and $1_{25(n-1)}$, assuming 1_o = 00, 1_{100} = 0. Thus on the exposure curve for E 1_t is the abcissa of the point with ordinate t%, and E_n is the group represented by the segment of y-axis between 25(n-1)% and 25n%. Hence E_1 is the quarter of the population suffering the greatest concentrations, and E_4 suffers the least. The choice of four groups was arbitrary, and a division into any number of groups could be performed in this way: it follows from the fact that all the pollution equations used are strictly monotonic increasing that the population groupings does not depend on the choice of equation E.

The mean reduction in the concentration of each pollutant experienced by the members of each group can be calculated, but the concentration according to one equation may be several times greater than that predicted by another the results would not then be comparable. This is solved by replacing "reduction" by "percentage reduction", (reduction expressed as a percentage of the original concentration). Suppose that link n has population p_n and a particular equation predicts an original concentration on n of 1_n and a reduction of $r_n 1$ N_t is the set of links n for which

$$1_{t-1} \leq 1_n < 1_t$$

and the "mean percentage reduction" for group E_t is

$$R^P(t) = 100 \times \frac{\sum_{n \varepsilon N_t} p_n \times r_n}{\sum_{n \varepsilon N_t} p_n \times 1_n}$$

Similarly, the "mean percentage change" for group E_t is

$$C^P(t) = 100 \times \frac{\sum_{n \varepsilon N_t} p_n \times |r_n|}{\sum_{n \varepsilon N_t} p_n \times 1_n}$$

Use of these devices quickly demonstrates their utility. The basic quantities of reduction and change caused confusion when used in the evaluation of restraint policies but the percentage results show sufficient agreement for useful conclusions to be drawn. The mean percentage reductions predicted by the eight equations for groups E_1, E_2, E_3, E_4 and for the complete population are presented in Figs 35-37 and show a fair measure of agreement between the curves produced by the various equations. The curves for C4 and O1a correspond so closely with those for C8 and C7, respectively, that they are omitted from the diagram for clarity.

The objective of "reducing atmospheric pollution" may now be examined. Atmospheric pollution tends to be regarded as homogeneous, whereas in fact it consists of a range of chemicals generated in different ways and it may be that changing a traffic management policy will increase the exposure to some of the pollutant gases and reduce the exposure to others. The order of the policies in Figs 33-37 is based on the overall effectiveness as presented in Fig 37. From this figure Supplementary Licensing gives rise for equations C4, C8 and O6a to a counter example, and Figs 33-37 provided several more. From the generally decreasing trend of the curves, a reduction in exposure to one pollutant is generally associated with reductions for other pollutants. There are of course many individual cases where this is not true.

Fig 38 shows the percentage change for the different policies, and comparison with the percentage reductions of Fig 37 shows that to some extent declining reductions are the result of declining total change; however, road pricing is the least effective policy in reducing atmospheric pollution as it maximises efficient capacity utilisation and yet it produces almost as much change as the most effective policy, fuel taxation, which has a global effect. This is one of the problems caused by the arbitrary choice of reference state, selected here as "unrestrained 1981" in order to standardise the shifts at a small level, and consequently halving the differential effects (of a 1967-1981 view) and reducing the size of the shifts sharply.

Figs 33-37 indicate reasonable agreement between the percentage reductions obtained from the various equations, so that to compare directly the differential effects of the policies on the four population groups one representative equation may be used. In Fig 39 the reductions predicted for the four groups by equation C8 are compared, and a similarity in the differential effects is noticeable. The corresponding changes are presented in Fig 40, and are representative of the changes calculated for the other equations. It is interesting that the quarter of the population that benefits most is not, (except in the case of fuel taxation,) the quarter worst afflicted. The reason for this lies in the nature of congestion: a driver who travels down a heavily congested street is already paying high generalised costs for this trip because of the time required, and the effect on his behaviour of

an additional charge will be less than for a less congested street. Thus a restraint policy will have diminished effect on congested routes. Equally, those least advantaged are the least exposed quarter, because traffic is diverted into just those suburban streets that were not previously busy.

The noise results show that only minimal changes from the arbitrary "1981" unrestrained base were brought about by these policies. Although the changes to the atmospheric pollution are much greater, the benefits are still less than might be expected from the reduced number of trips. The reason for this may will be that drivers are led to make longer journeys in order to avoid paying charges, so that a reduction in the number of journeys is partially offset by increased journey length. It is significant that in the case of fuel taxation, where all trips are affected by the policy, the effectiveness of the policy in reducing pollution is much greater than other policies, although the mean change is little higher. Of course, when these policies are referred to the present (eg 1967) the differentials will be considerably increased, though at the expense of the pure differential study of 1981 presented here

These methods lead to useful results concerning the effects of congestion, but the main conclusion to be drawn is that by using the proportional reduction the effects of the diversity of empirical equations may be avoided and useful conclusions may be drawn. The diversity of equations available indicates the nature of the difficulties of reliably predicting pollutant concentrations from the variables available within a transportation model. This limitation is not easily dismissed, and so the use of this approach is presently inescapable. There are notable distributional effects, but in view of the greater importance generally attached to noise due to its ready perception, it may be appropriate to concentrate on the distributional aspects of the noise changes and merely obtain overall results for the changes in atmospheric pollution for future applications of environmental appraisal at this strategy level.

5.6 The railway triangle as an environmental area

The results so far given refer to the whole of the scenario network: in order to correct this inbalance some of the results will now be provided in a compatible format for the restraint area itself - the railway triangle.

The various measures of traffic restraint studied have been broadly designed to alleviate congestion in the inner part of Coventry, which is roughly consistent with the "Railway Triangle". The relative effectiveness of these policies in reducing congestion has already been discussed, and the social impacts covered in 4.2. Here altered exposure to noise is analysed for just this area. The population assigned to that part of the network within the railway triangle total 10,073, and

their exposure is very similar to that of the complete population, except that 2% more experience less than 70 dB.

	Population of Railway Triangle who, in the unrestrained situation, experience the following L_{10} levels	
>80 dB	3.9%	390
75-80 dB	91.9%	9260
70-75 dB	1.2%	120
<70 dB	3.0%	300

The reduction and change per head for each policy is given in Table 11, which may be compared with Table 10 (for the whole network).

It is clear that the ranking by effectiveness in the railway triangle does not agree with that for the entire city. Specifically the performance of supplementary licensing is particularly poor and brings about an overall increase within the triangle, although its effect on the entire city is virtually nil. The conclusion must then be drawn that, far from benefiting the city centre, supplementary licensing benefits the outer parts of the city to the detriment of the city centre with respect to noise exposure. This may be instructive to compare with 4.2.

The various restraint measures generally produce as expected, above-average changes in the city centre, but these changes are not necessarily beneficial to population in the city centre. The unequal distribution of the population between the four L_{10} ranges does not allow great weight to be placed on a simple comparison; in fact, for the dominant column relating to the population exposed to the range 75-80 dB only for supplementary licensing is the change for the city centre population less beneficial than the average reduction. It is clear, however, that some results of traffic restraint are counter-intuitive when sub areas such as the triangle are examined more closely.

5.7 Pedestrian impacts

Difficulty experienced in crossing the road is one effect of road traffic on the local population. An appropriate model has been included in the PANIC system. The "delay" involved in crossing the road is calculated, and is the time taken from the decision to cross to the arrival at the far side of the road. The pedestrian in a congested street is particularly exposed to traffic-generated pollution concentrations, and consequently a model is included to predict the number of pedestrians on each street: this makes it possible to analyse the exposure to

pollution of the "pedestrian population" and compare this with the exposure of the "resident population". It is evident that a further stage is still to be added: the exposure profile time variation to match to varying traffic flows. It would then become desirable to investigate double counting by multiple use of the same people in different roles (driver, pedestrian, resident, other workers, etc).

Unfortunately, few surveys have been carried out to provide the necessary empirical equations even for the simple prediction of numbers of pedestrians. Those used in the work described here are derived from a survey conducted in Coventry.[3] This was confined to suburban shopping streets, as it has been found that these were the main areas in which the numbers of pedestrians could be predicted from the limited land-use data available. Nonetheless, these equations are applied to all streets of the model. In addition to the number of pedestrians on each pavement the equations predict the number of pedestrians in an hour trying to cross, and the delay in crossing. No great reliance can be placed on these equations because of their limited scope and the lack of similar equations for comparison, and their results are included to indicate the use that may be made of the pedestrian model.

All the various methods used to analyse the impact of pollution on the population could be repeated using the predicted pedestrian population in place of the resident population. Only the exposure curve methods are used so as to indicate the differences in exposure between the two populations. The pollutant concentrations and L_{10} levels used throughout have been kerbside values, and so any increase in exposure found will be solely due to a relative concentration of pedestrians on busy streets, for the shielding effect of buildings have not been included.

In Fig 41 that L_{10} exposure curves of the residential and pedestrian populations are compared, and it is seen that the most exposed fifth of the latter is exposed to significantly higher L_{10} levels than the corresponding part of the former. There is thus a shift of 1-1½ dB among those most exposed, and this is repeated in the proportional shifts for the atmospheric pollutants shown in Fig 42 and 43. This shows considerable shift for the most exposed fifth, but only slight shifts for the remainder of the population. This would suggest that if a sifferential impact analysis were to be repeated with this pedestrian population in place of the residential population it would favour those policies which secure reductions in pollution for the busiest streets. If however the base state were to be altered to 1967 (restrained <u>or</u> unrestrained), it could once more reverse this emphasis. The identification of these pedestrians, and their degree of correspondence to populations subject to exposure at home, would be essential if double counting of benefits or impacts were to be eliminated.

The values obtained for the mean pedestrian crossing time are presented in Table 12. All the restraint policies bring some reduction in pedestrian delay. Due to the structure of the equations available the delay includes a period of walking time which is constant for all simulations, and this is subtracted to give the mean waiting time: the mean waiting time is reduced by up to 14% by traffic restraint.

It must be emphasised that the results of this section are obtained by applying equations based on a limited survey of suburban shopping streets at a given date to the complete city, for the future. As there are only equations available, it must be stressed that the data were collected in Coventry itself. These results have been included to give some indication of how such equations may be incorporated in the analysis, and affect the interpretation and evaluation of the environmental conditions that we have forecast.

5.8 Further developments in environmental impact appraisal

The PANIC system was set up as an intrinsic part of the overall traffic restraint systems study, and used in this work entirely to describe the environmental consequences of simulated traffic flows. The results confirm that an interaction between the environmental model and the assignment stage of the transportation model should be added in order that assignments may in future be influenced by environmental consequences.

Alternative methods of linking the environmental model with the assignment stage have been previously proposed .[26] The most promising of these involve the setting of environmental standards, and the imposition of tolls when the traffic in a street causes violation of these standards. A reassignment of traffic which more nearly satisfies the environmental standards would result and an iterative process would lead to an assignment which would satisfy the standards economically if they were feasible. If the standards were infeasible, violations would be reduced to a minimum. This would determine (a) whether the standards were feasible, and (b) if so, what the minimum cost of meeting them would be to the road users.

On the basis of this pioneering work, only noise standards could be examined because of the limitations of the empirical equations employed. The shortcomings of the noise prediction equations are largly explicable to varying local background noise levels, and it would be possible to produce externally a set of predicted background levels that would increase the predictive power of the environmental model and improve the quality of such an iterative solution of the standard feasibility problems.

For any useful future development, changes must be made in the selection of parts of the city to be included in the model. The choice of what to include has historically been based on the needs and capabilities of the traffic assignment.

These conflict with the requirements of any model for environmental appraisal eg.the selection of roads for the network used here exclude the majority of residential housing, as the busier roads are included to improve the effectiveness and cost of the assignment. However, these busier streets are unattractive for housing. But if a part of the traffic from these residential areas could be diverted onto the main network the increase in noise here would be marginal whereas there would be a considerable reduction in back-street noise. The inclusion or ommission of these back-streets has an important effect on the range of application of the model, and must therefore be considered in the light of these new assessment requirements.

The key problems raised by the design and implementation of an environmental impact model have been discussed using the PANIC system of models as part of a study of fiscal traffic restraint so as to illuminate some of the environmental problems and their scale. These difficulties are particularly acute in the prediction of the concentration of atmospheric pollutants. It has however proved to be possible to obtain consistent results without requiring the complexity of multiple emission and diffusion models. In view of the comparative appraisal nature of the study, the emphasis lies on differential impacts. The environmental consequences of a change in traffic flow have been shown to vary significantly. The critical importance of the choice of reference level for environmental impact forecasts has emerged as a central feature, requiring close co-ordination of modelling and option evaluation and specification and environmental appraisals. The results of forecasts of shifts between policies in a given year, and of shifts between years for a given policy have very different implications: if the future year is regarded as the start point of a policy, then the results given here are appropriate. Unfortunately the basic demand for that year exceeds supply, and the choice of instrument to make travel possible at or near that level is the real question posed. Consequently a full environmental appraisal would have to be (1981 + restraint policy) - (1967 + restraint policy) - or possibly - (1967 only) - to be useful or relevant. The results given here are to give a technical appraisal of the techniques and character of restraint policy.

6. SUMMARY

The task set out was to develop a set of modelling, prediction, and appraisal tools and to apply them to a moderately realistic test area. The objective was to assess the general scale of economic, traffic, social, and environmental effects that might result from the introduction of any one (or more) of a range of flexible traffic restraint policies. A complete systems analysis of the requirements was carried out, and several novel techniques and models were initiated, in addition to special surveys where required. A computer system incorporating all these innovations has been fully documented elsewhere.[27]

The tools were successfully built, and the process of testing out techniques and policy simulations has provided a broad appraisal of traffic restraint as a transportation planning policy. The scale and direction of many different types of impacts, benefits, and disbenefits has been achieved, and like all integrative researc programs the number of new problems posed exceed the number solved. It is clearly inescapable that as social, distributive, economic, environmental, geographical, traffic and transportation issues become more closely limited, appraisal techniques must follow. This report covers a first broad attempt to bring more such issues under a single numerate roof than has been previously possible.

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TABLE 1 - "1967" SCENARIO

"1967" SCENARIO RESULTS: FIGURES IN £1967											
RESTRAINT	TOLL CHARGED 1p=2.4d	FINAL AVERAGE SPEED (MLS/HR)	FINAL TOTAL PCU	TOTAL TOLL REVENUE (£/HR)	PRIVATE VEH BENEFIT (£/HR)	GOODS VEH BENEFIT (£/HR)	EXTRA BENEFIT FROM XFERRED TRIPS (£/HR)	NET BENEFITS (£/HR)	PRIVATE TOLL REVENUE (£/HR)	REVENUE FROM XFERRED TRIPS (£/HR)	EXTRA REVENUE FROM BUS PASSENGERS (£/HR)
BASE	-	27.1	61750								
PARKING	5D	28.3	62000	240	- 130	- 35	9	80	170	44	0
	10D	28.9	60500	430	- 260	- 80	10	120	300	100	0
	20D	29.3	58500	760	- 490	-170	30*	130	500	220*	1
	30D	29.5	57250	1040	- 700	-280	60*	120	640	360*	1
SUPPL. LICENCE	5D	29.0	60750	510	- 310	- 80	30	140	360	150	0
	10D	29.3	58750	900	- 610	-190	50	150	600	220	5
	20D	29.6	55500	1500	-1170	-465	75	- 55	915	440	12
	30D	29.5	54000	1980	-1610	-700	115	-220	1050	580	30
CORDON RAILWAY TRIANGLE	10D	29.0	59250	950	- 750	-270	60*	- 4	600	280*	10*
	20D	29.2	57250	1730	-1170	-490*	90*	160	1020	375*	20*
	30D	29.3	56000	2210	-1430	-830	110	60	1150	460	30
	50D	29.7	54250	3270	-2030	-1500	140	-120	1520	640	30
	80D	29.9	57250	4880	-2600	-2560	170	-115	2070	790	40
CORDON (LARGE AREA)	10D	29.2	59250	1050	- 730	- 200*	60*	230	500*	260*	20*
	20D	28.1	57250	1750	-1450	- 530*	85*	-140	630*	370*	35*
COLLAR AND PARKING	-	23.8	59500	-	-1200	- 755	-320	-2280	-	400	0
	10D	24.3	57250	380	-1360	- 880	20	-1840	250	450	20
	20D	24.7	56000	690	-1500	- 1070	-380	-2190	430	550	5
PRICING RAILWAY TRIANGLE (PER MILE)	6D	29.0	61500	520	-360	- 90	30	110	350	110	3
	12D	28.7	59500	870	-700	- 210	60	20	525	240	20
	25D	28.6	57500	1380*	-1190	- 520	80	-250	650	410	20
	50D	28.1	55250	2600*	-1740	-1300	100	-360	1100	570	30
	100D	28.4	53500	4470*	-2180	-2640	115	-230	1590	675*	50*

Continued/...

Table I Continued

RESTRAINT	TOLL CHARGED 1p=2.4d	FINAL AVERAGE SPEED (MLS/HR)	FINAL TOTAL PCU	TOTAL TOLL REVENUE (£/HR)	PRIVATE VEH BENEFIT (£/HR	GOODS VEH BENEFIT (£/HR)	EXTRA BENEFIT FROM XFERRED TRIPS (£/HR)	NET BENEFITS (£/HR)	PRIVATE TOLL REVENUE (£/HR)	REVENUE FROM XFERRED TRIPS (£/HR)	EXTRA REVENUE FROM BUS PASSENGERS (£/HR)
PRICING CENTRAL AREA (PER MILE)	12D 25D 50D	28.7 28.3 28.2	60750 59250 57500	610 980* 1920	-530 -880 -1310	-160 -380 -940	40 60 80	- 40 -210 -250	350 460 800	150 280 440	15 20 30
AREA PRICING	- -	29.3	59500	655	-320	- 90*	60*	310	420*	240*	20*
PRICING LARGE AREA (PER MILE)	6D 12D 50D	29.1 29.1 28.6	61000 58750 56000	640 1080 1730	-450 -850 -1460	-110 -280 -670	40 70 100	120 10 -290	420 640 880	140 300 520	3 12 30
AREA PRICING (NETWORK)	-	31.3	53250	2430	-1410	-410*	120*	750*	1200*	650*	40*
PARKING 50/50 SPLIT	20D	29.4	59500	270 (PRI-VATE ONLY)	- 240	- 30*	50*	50	270*	220*	20*
OPTIMUM TOLL-SINGLE LINK	-	-	-	2410	1560		-	850	-	-	-

* extrapolation

TABLE 2: SIMULATION RESULTS: ALL FIGURES IN £1970

YEAR	POLICY	TOLL CHARGED	CAR EQUIVALENT JOURNEYS (GOODS + PRIVATE p.c.u.	TOTAL REVENUE (£/HR)	TOTAL BENEFIT (NO OPERATING OR INSTALLATION COSTS FOR BUSES) (£/HR)	EXTRA BENEFITS FROM TRANSFERRED TRIPS	REVENUE FROM TRANSFERRED TRIPS
1) AREA VARIATIONS							
	AREA ROAD PRICING	1p = 2.4d					
1981	PRICING: RAILWAY TRIANGLE	20d/Mile	118000	4100	- 600		
		40d/Mile	116500	6700	- 100		
		70d/Mile	112750	9800	- 30	300	1600
1981	PRICING LARGE AREA	2x	115500	10600	1400	400	2600
		3x	110250	14100	1900	800	3500
2) COMPARISON OF RESTRAINT IN RAILWAY TRIANGLE							
1981	BASE	-	125000	-	-	-	-
1981	SUPPL. LICENCE	40d	117000	7300	4000		
		70d	114000	11200	5500		
		100d	110500	14000	5300	400	1400
		130d	108500	15700	4300		
1981	PARKING	25d	120250	2000	700	0	170
		40d	119750	3000	1200	0	
		55d	117000	3800	1400	11	370
		70d	116000	4700	900	9	400
1981	CORDON	25d	121000	5600	4900	0	240
		40d	118000	8200	5200	65	830
		70d	115250	11300	3900	270	1120
		100d	111500	13200	1900	620	1820
1981	AREA PRICING	1x	119000	3200	1100	0	680
		2x	116000	7700	2300	185	1060
		3x	113500	10400	40	420	1350

TABLE 3: "1981" SCENARIO: THE EFFECTS OF JOINTLY VARIED PARKING AND OTHER RESTRAINT MEASURES (FIGURES in £1970)

POLICY	TOLL CHARGED	GOODS PRIVATE p.c.u.	TOTAL REVENUE (£/HR)	NET BENEFIT £/HR	EXTRA BENEFITS FROM TRANS-FERRED TRIPS	REVENUE FROM TRANSFERRED TRIPS
BASE	-	125000	-	-	-	-
CORDON +PARKING	60D (80D (	109750	14585	5400	400*	1200*
CORDON +PARKING	40D (30D (	115250	10100	4700	120	900
CORDON +PARKING	40D (45D (	114000	10900	5300	170	960
CORDON +PARKING	40D (60D (	113500	11740	5900	210	960
CORDON +PARKING	40D (80D (	112000	12600	5400	260	1020
CORDON +PARKING	40D (100D (	111250	13500	5500	320	1040
CORDON +PARKING	20D (80D (	114500	9700	4700	90	760
CORDON +PARKING	20D (100D (	114000	10600	5000	150	670
CORDON +PARKING	50D (140D (	108750	16000	5600	460	1440
CORDON +PARKING	40D (120D (	110950	14500	5700	370	1020

* results of interpolation curves of all component factors of the net benefit

TABLE 4: "1981" SCENARIO: LINK BY LINK PRICING IN THE RAILWAY TRIANGLE: THE EFFECTS OF SCALING IDEALISED ROAD PRICING CHARGES

Figures in units of 1970 pounds.

OPTIMAL TOLL SET <+>	TRIPS (PRIVATE + GOODS p.c.u.)	TOLL REVENUE	NET BENEFIT
0.5 x <+> (EQUAL TOLLS)	117500	7900	1060
0.75 x <+> (EQUAL TOLLS HIGH)	116750	9500	5000
1.0 x <+> (EQUAL TOLLS HIGH)	115000	10800	4600
1. 25 x <+> (EQUAL TOLLS)	112000	11300	1700

TABLE 5: "1981" SCENARIO: CORDON (OUT BOUND ONLY) AND PARKING (OUT BOUND ONLY) AT A VERY HIGH TOLL

A) Cordon Outward only across Railway Triangle

TOLL CHARGED	GOODS AND PRIVATE pcu	TOTAL REVENUE (£/HR)	NET BENEFIT (EXC. BUS)
50D	119500	7200	5100
80D	118000	9800	5200
100D	116750	11100	5000

B) Parking (outbound only) at a very high toll (200D) on central area

200D	118500	5800	1500

TABLE 6: "1981" SCENARIO: EFFECTS OF INCREASING RESOURCE AND TAX COSTS AS A DEFINITE RESTRAINT POLICY

POLICY	AV. SPEED (MLS/HR)	TRIPS	CONSUMER LOSS (£/HR)	TAX COSTS (£ /HR)	RESOURCE COSTS (£/HR)	BENEFIT (SAVING) £ /HR
BASE		125000	-	24900	153800	0
NET COST x 2 (% tax fixed)	20.2	104500	- 21500	19500	120400	11900
RESOURCE COSTS x 2 + TAX (TAX CONSTANT)	20.1	105500	- 21900	19600	121200	10900
NET COST x 1.5 (% TAX FIXED)	18.8	111750	- 14200	21200	131000	8600

TABLE 7: "1981" SCENARIO:
THE IMPACT OF TRAFFIC RESTRAINT ON TRAFFIC DEMAND IN THE RAILWAY TRIANGLE

POLICY	TRIPS IN/OUT RAILWAY TRIANGLE	% REDUCTION OVER BASE
BASE	42300	-
CORDON 40D	39100	7.6%
PARKING 55D	33300	21. 4%
SUPP.LIC.100D	28000	34%
PRICING 1.2D (EX. AREA)	36800	13%
FUEL TAXATION: 1. NET COSTS x 2 (% of tax fixed)	35500	16%
2. RESOURCE COSTS x 2 (Tax charges constant)	35800	15.4%

TABLE 8

The equations used in the environmental analysis.

The following equations have been used; the numbering agrees with reference (3).

				Reference
N1	:	$L_{10} = 27.4 + 0.3p + 20.4 \log V - 0.18p \log V + 8.0 \log Q + 0.05\, p \log Q - 16 \log 2$	(dBA)	(24)
N5	:	$L_{10} = 52.46 + 6.73 \log (Q(1+0.09p))$	(dBA)	(3)
C1	:	$CO = 2.26 + 0.14R - 0.63A + 0.03Q/V + 2.368Q/(W.V)$	(ppm)	(25)
C2	:	$CO = 3.66 - 0.69A + 0.022\, QT/V + 2.87Q/(W.V)$	(ppm)	(25)
C3	:	$CO = 1.69 + 0.00269\, Q$	(ppm)	(26)
C4	:	$CO = 2.96 + 0.00096\, Q + 0.0000045\, Q^2$	(ppm)	(26)
C5	:	$CO = 0.26 - 0.0002\, Q + 0.000026\, Q^2$	(ppm)	(3)
C6	:	$CO = 0.74 - 0.00056\, Q + 0.0000029\, Q^2$	(ppm)	(3)
C7	:	$CO = 0.574 + 0.0038\, Q$	(ppm)	(3)
C8	:	$CO = 0.648 + 0.001\, Q + 0.0000015\, Q^2$	(ppm)	(3)
O1a	:	Total Oxides of Nitrogen (NOX) $= 0.032 + 0.00025\, Q$	(ppm)	(3)
O2	:	Total oxides of Nitrogen (NOX) $= -0.548 + 0.000822\, Q$	(ppm)	(26)
O4	:	Smoke $= 9.49 + 0.66\, Q$	($\mu gm.m^{-3}$)	(26)
O5	:	Lead $= 0.0431 + 0.000747(1.0.01pQ)$	($\mu gm.m^{-3}$)	(26)
O6a	:	Hydrocarbons $= 3.28 + 0.00035Q + 0.0000005Q^2$	($\mu gm.m^{-3}$)	(3)

where Q = total two-way flow
p = percentage of total flow that is of goods vehicles
V = mean velocity (m.p.h.) of flow
R = ambient temperature in degrees centigrade
A = mean wind speed (m.p.h.)
T = Crompton and Gilbert arrival pattern index

The pedestrian delay equations for the evening peak were derived from equations in reference (2).

Number of pedestrians = $13.87 + 0.0243X$

Number of crossing per hr = $137.4 + 0.2X$

Delay per person (secs) = $2.04 + 0.586W + 0.565Q$

Where W is the width (metres) of the road and X is the total retail and service trades floor space (square metres).

TABLE 9

The percentage of the population experiencing different reductions in peak hour L_{10} in "1981", referred to a hypothetical "1981" unrestrained state.

Restraint Method	Exposure as unrestrained 1981 conditions Original Exposure	Reduction (dB)			Increase (dB)										
		2½-3½	1½-2½	½-1½	Little change	½-1½	1½-2½	2½-3½	3½-4½	4½-5½	5½-6½	6½-7½	7½-8½	8½-9½	9½-10½
Fuel Taxation	$L_{10}<70$	0.32	1.34	0	0.06	0.47	0	0.16	0	0		0.05			
	$70<L_{10}<75$			0	3.34	1.20	0.68	0.18	0.36	0.57					
	$75<L_{10}<77.5$			1.68	41.80	3.33	1.91								
	$77.5<L_{10}<80$			1.21	35.55										
	$L_{10}<80$			0.28	5.47										
Supple-mentary Licence	$L_{10}<70$	0.32		1.34	0.69	0.06	0	0	0	0			0		0
	$70<{}_{10}<75$			1.20	4.41	0.01	0	0.19	0	0.36			0.15		0
	$75<L_{10}<77.5$			2.54	42.50	1.51	0.19	1.92	0						0.6
	$77.5<L_{10}<80$			2.18	34.44				0.14						
	$L_{10}<80$			0.04	5.71										

Note: "Little Change" indicates that there was either an increase or a reduction of less than 0.5 dB

TABLE 10

The mean reductions and mean changes from six policies in 1981, referred to a hypothetical 1981 unrestrained state

Policy	Reduction per person (dB)					Change per person (dB)				
Noise band in unrestricted 1981 situation	$L_{10}>80$	$77.5<L_{10}<80$	$75<L_{10}<77.5$	$70<L_{10}<75$	$L_{10}<70$	$L_{10}>80$	$77.5<L_{10}<80$	$75<L_{10}<77.5$	$70<L_{10}<75$	$L_{10}<70$
Outward cordon	0.037	0.060	0.012	0.088	0.699	0.095	0.145	0.180	0.861	1.171
Fuel taxation	0.278	0.169	0.022	-1.215	0.843	0.278	0.197	0.324	1.241	1.941
Cordon	0.081	0.052	0.004	0.297	1.150	0.116	0.164	0.191	0.651	1.344
Parking	0.046	0.034	0.026	0.171	0.153	0.046	0.153	0.154	0.358	1.031
Supplementary licence	0.085	0.056	0.078	-0.234	1.148	0.155	0.225	0.320	0.903	1.272
Pricing	0.077	-0.005	0.007	-0.433	-1.113	0.133	0.244	0.252	0.833	3.051

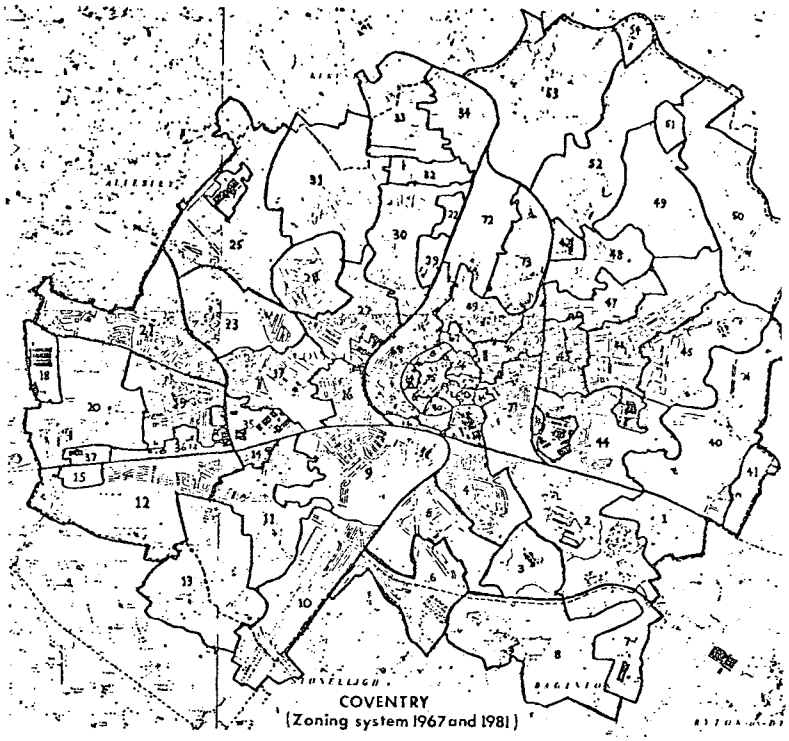
TABLE 11

Original level	Mean reduction in hourly L_{10} per head (dB) in peak hours in the railway triangle				Mean total change in hourly L_{10} per head (dB) on peak hours in the railway triangle			
	$L_{10}<70$	$70<L_{10}<75$	$75<L_{10}<80$	$L_{10}<80$	$L_{10}<70$	$70<L_{10}<75$	$75<L_{10}<80$	$L_{10}<80$
Area point pricing	2.56	4.17	0.11	0.49	8.90	4.17	0.43	0.49
Fuel (Tax % of price Constant)	2.32	-2.16	0.15	0.15	2.32	2.16	0.23	0.14
Fuel (Tax Charge Constant)	2.29	-1.90	0.10	0.13	2.35	1.90	0.18	0.13
Parking	2.84	-1.29	0.09	0.03	2.84	1.29	0.14	0.03
Supple-mentary Licence	2.89	9.09	-0.42	0.22	2.88	9.09	0.69	0.22
Cordon	2.28	-4.52	0.07	0.11	2.36	4.52	0.31	0.13
Outward Cordon	-1.22	-0.25	0.05	0.18	2.33	9.09	0.35	0.18
Cordon + Parking	2.37	-1.93	0.06	0.18	2.37	1.93	0.40	0.18

TABLE 12

Pedestrian delays in 1981, referred to an unrestrained 1981 state.

Policy	Mean delay (secs)	Waiting time / Pre-restraint Waiting time (%)
Do-nothing	25.08	100.0
Outward Cordon	23.82	94.0
Fuel Taxation	21.81	84.3
Cordon	23.97	94.6
Parking	24.41	96.8
Supplementary Licence	23.16	90.8
Road Pricing	23.95	94.5

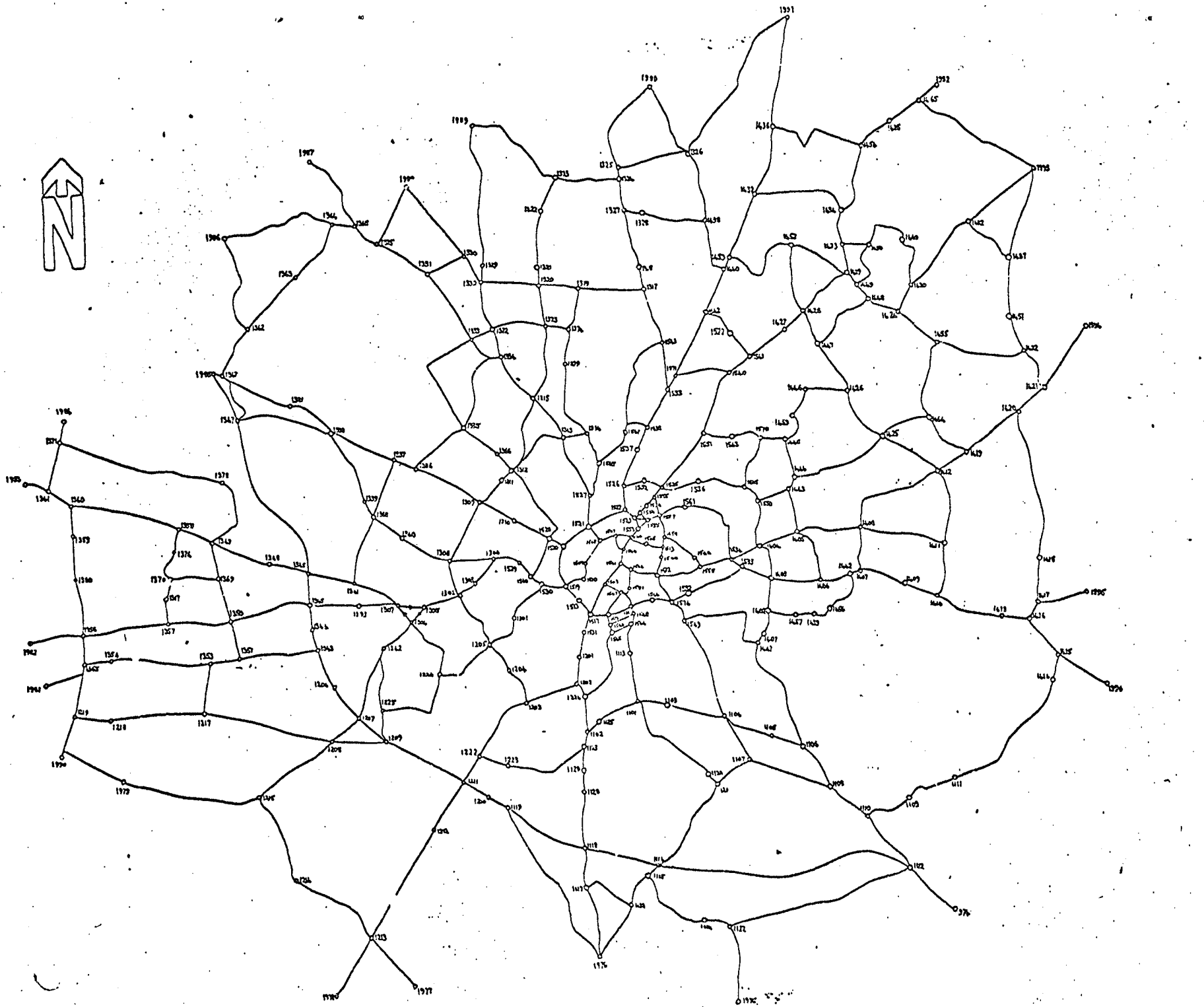


COVENTRY 1967 RAILWAY TRIANGLE RESTRAINT AREA

COVENTRY 1981 RAILWAY TRIANGLE RESTRAINT AREA

AREA BOUNDARY

ADDITIONAL NODE



COVENTRY

1967 HIGHWAY NETWORK

TRRL SCENARIO

CITY CENTRE

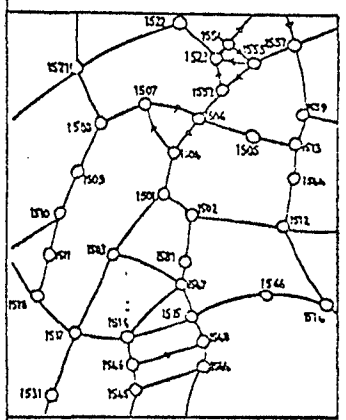
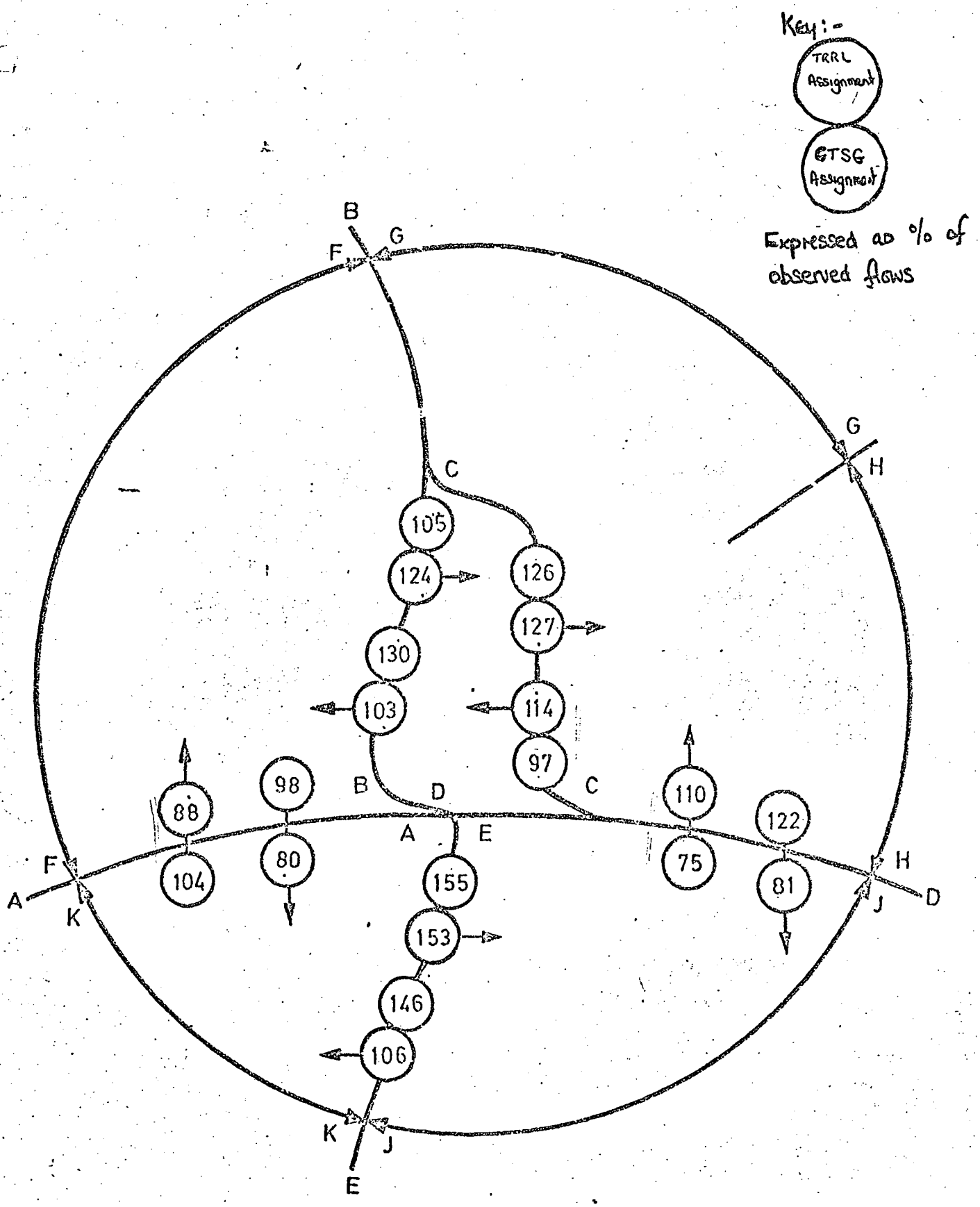


FIGURE 2 :

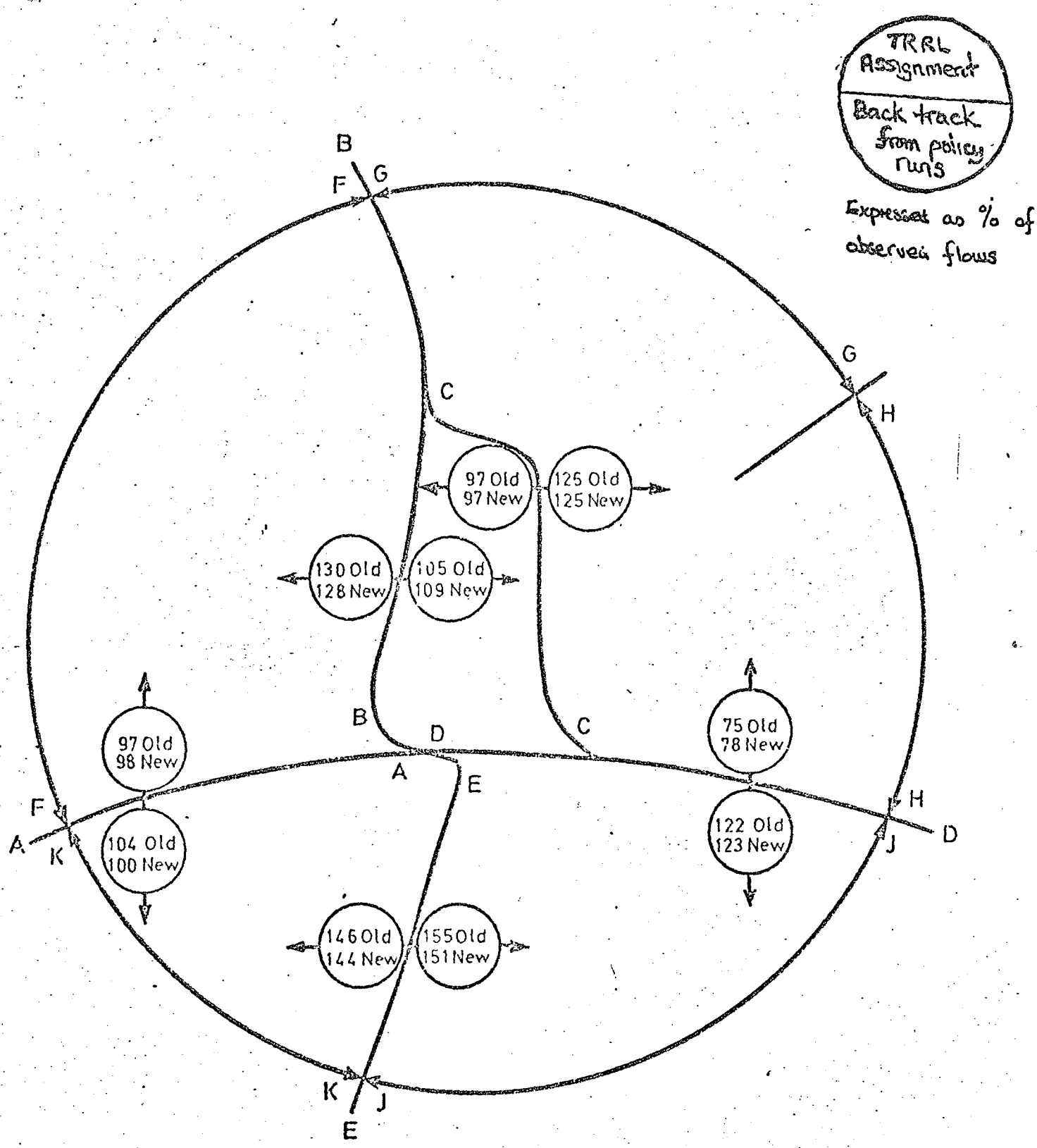
ROAD NETWORK USED FOR '1967' SCENARIOS.



GTS ASSIGNMENT OF RESIDENT VEHICLE FLOWS

1967 PEAK HOUR MODEL -
CROSS CORDON AND CROSS SCREEN LINE FLOWS

FIGURE 3 (a)



TRRL ASSIGNMENTS OF GOODS AND PRIVATE VEHICLE FLOWS

1967 PEAK HOUR MODEL -

CROSS CORDON AND CROSS SCREEN LINE FLOWS

FIGURE 3(b)

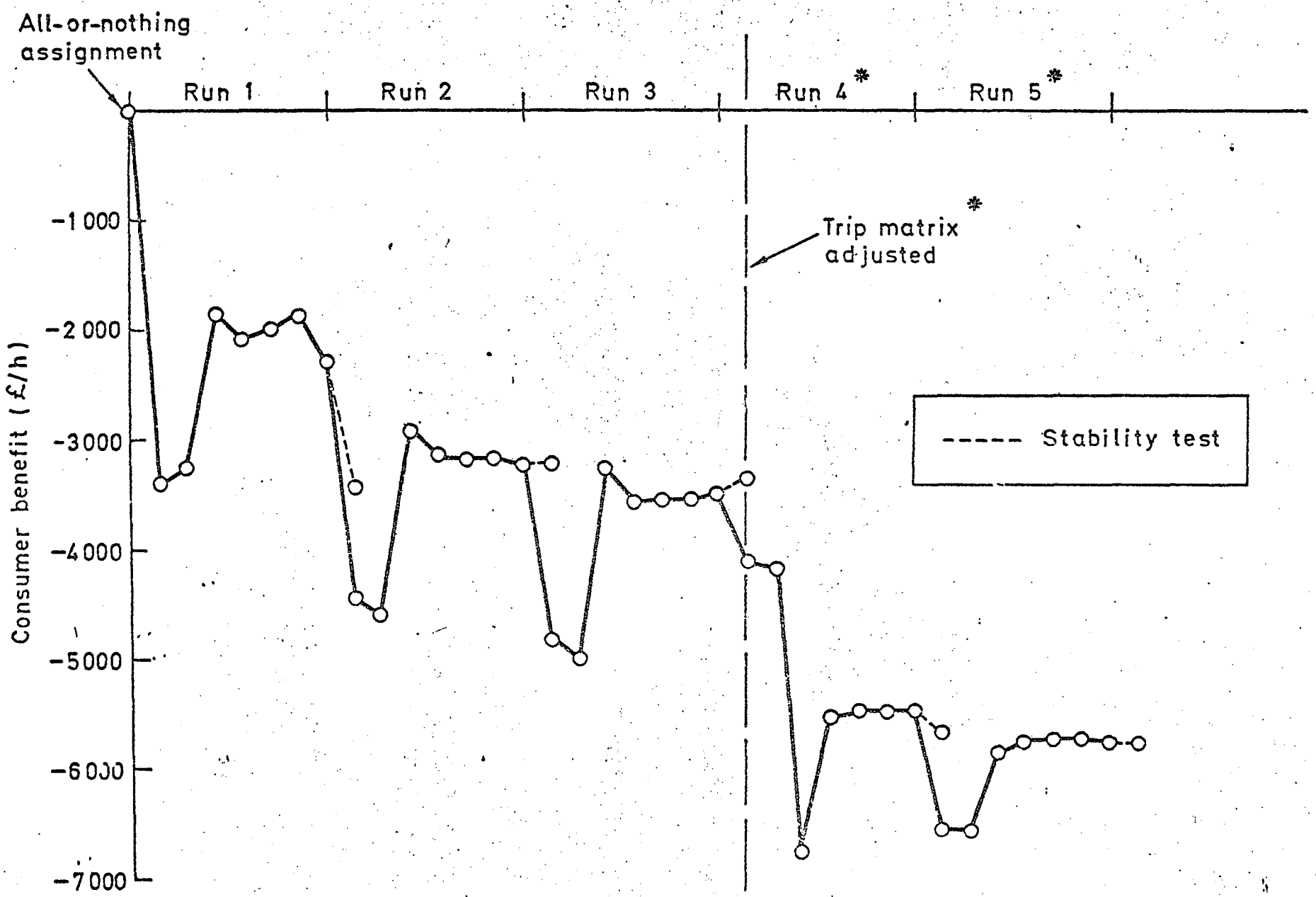


FIGURE 4: COVENTRY 1967 ASSIGNMENT CONVERGENCE BY SUCCESSIVE PERTURBATIONS.

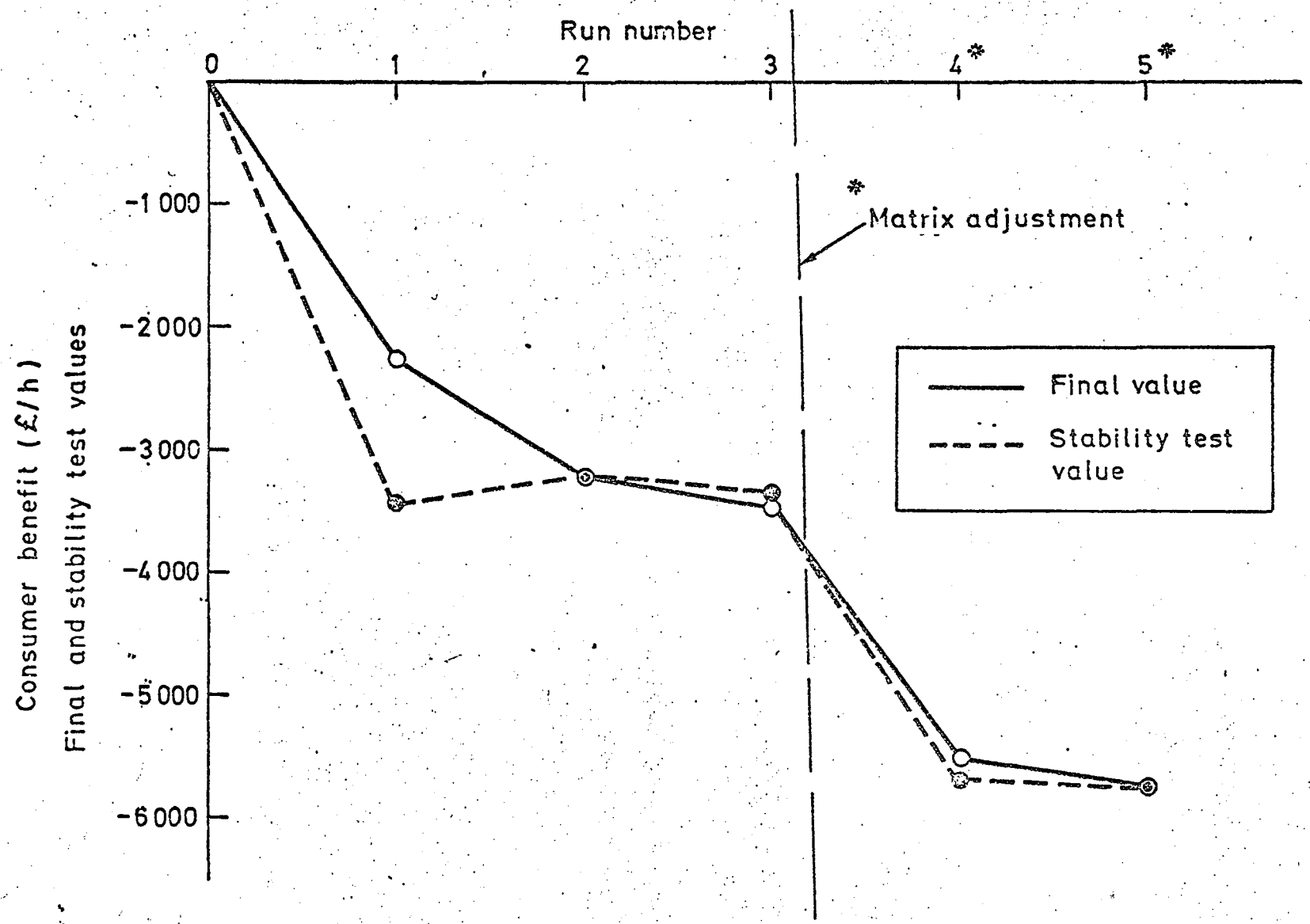
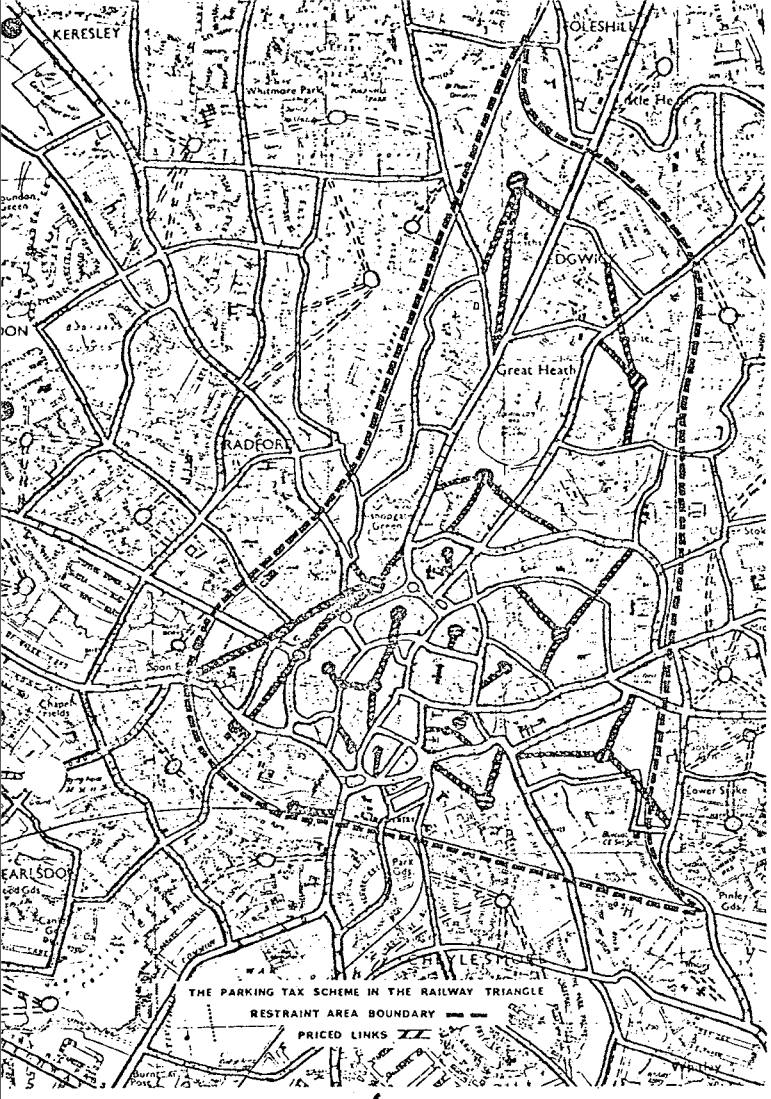
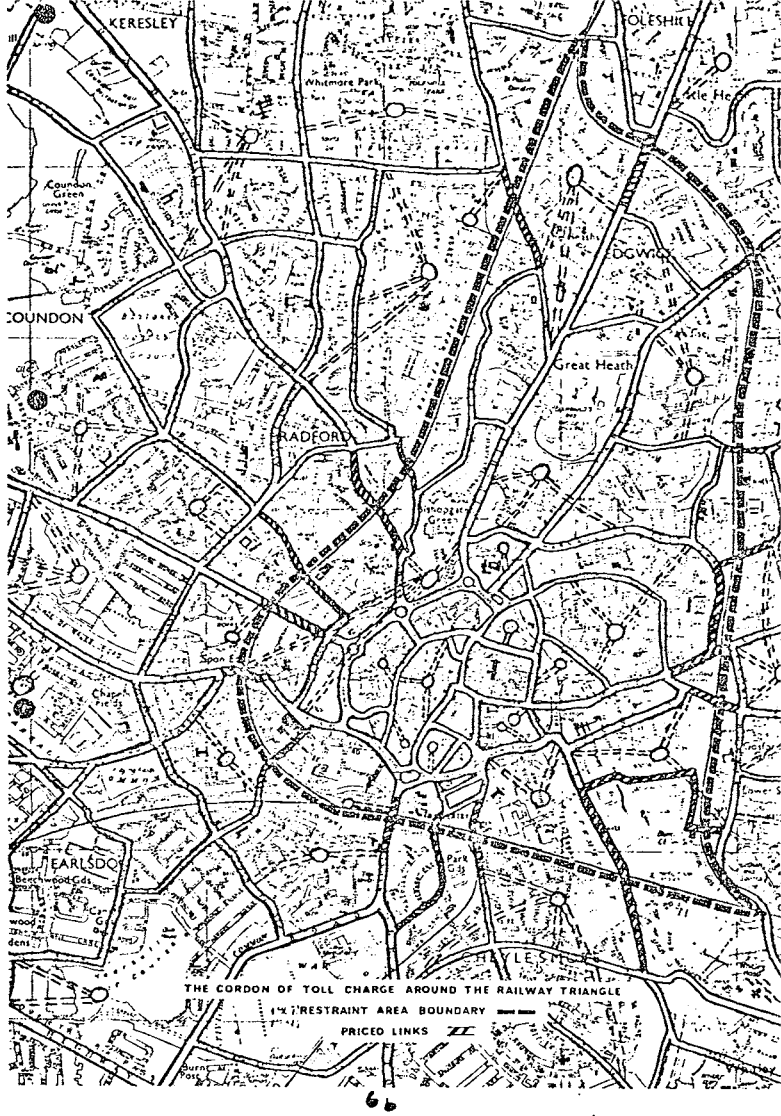


FIGURE 5 : COVENTRY 1967 ASSIGNMENT

LIMITS FOR CONVERGENCE MONITORING

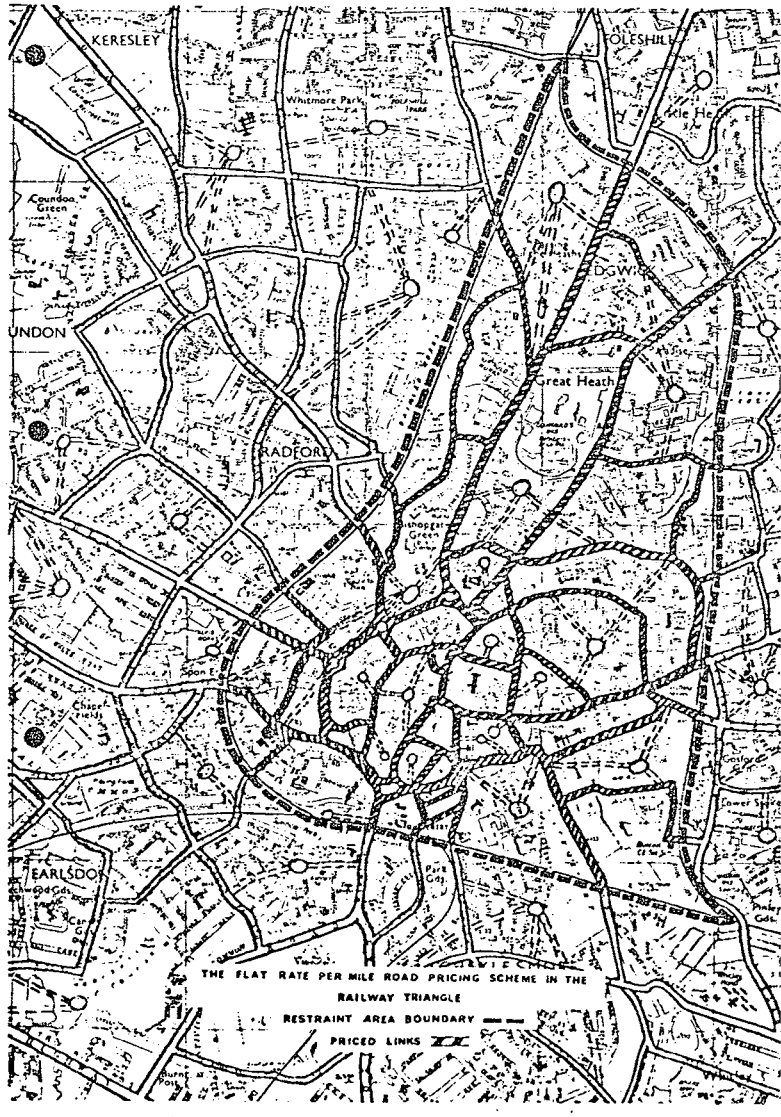

KERESLEY
OLESHILL
Whitmore Park
Great Heath
RADFORD
EARLSDON
THE PARKING TAX SCHEME IN THE RAILWAY TRIANGLE
RESTRAINT AREA BOUNDARY
PRICED LINKS

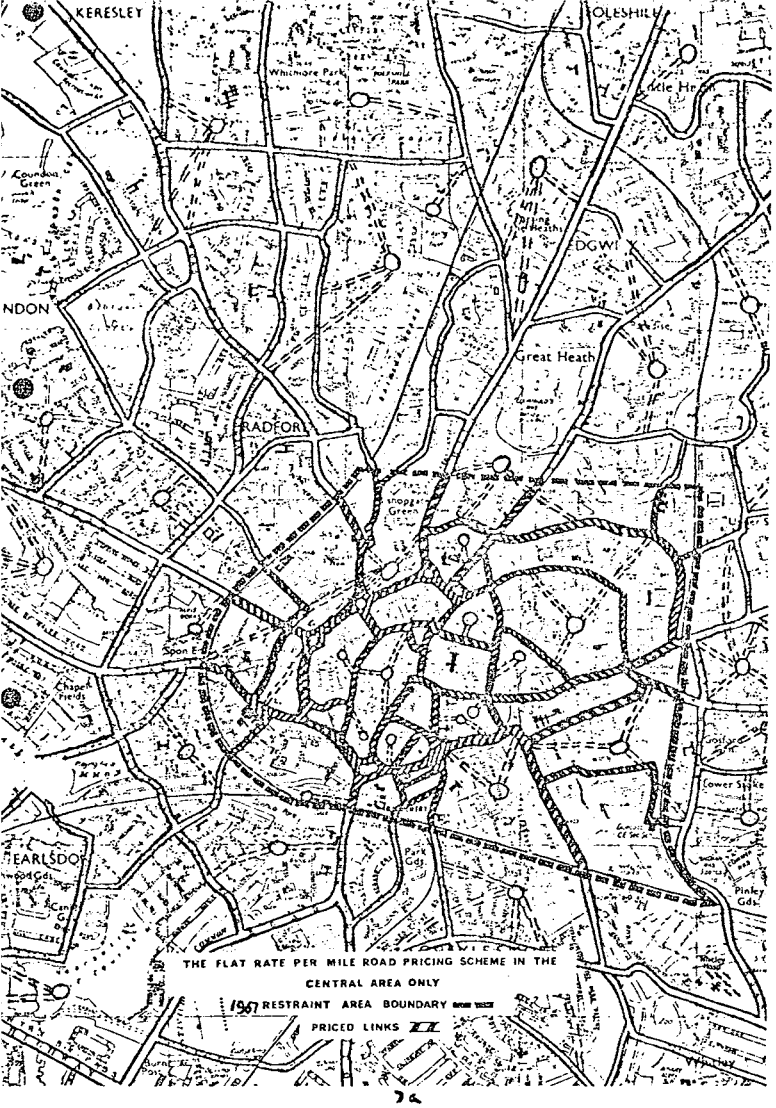
6a

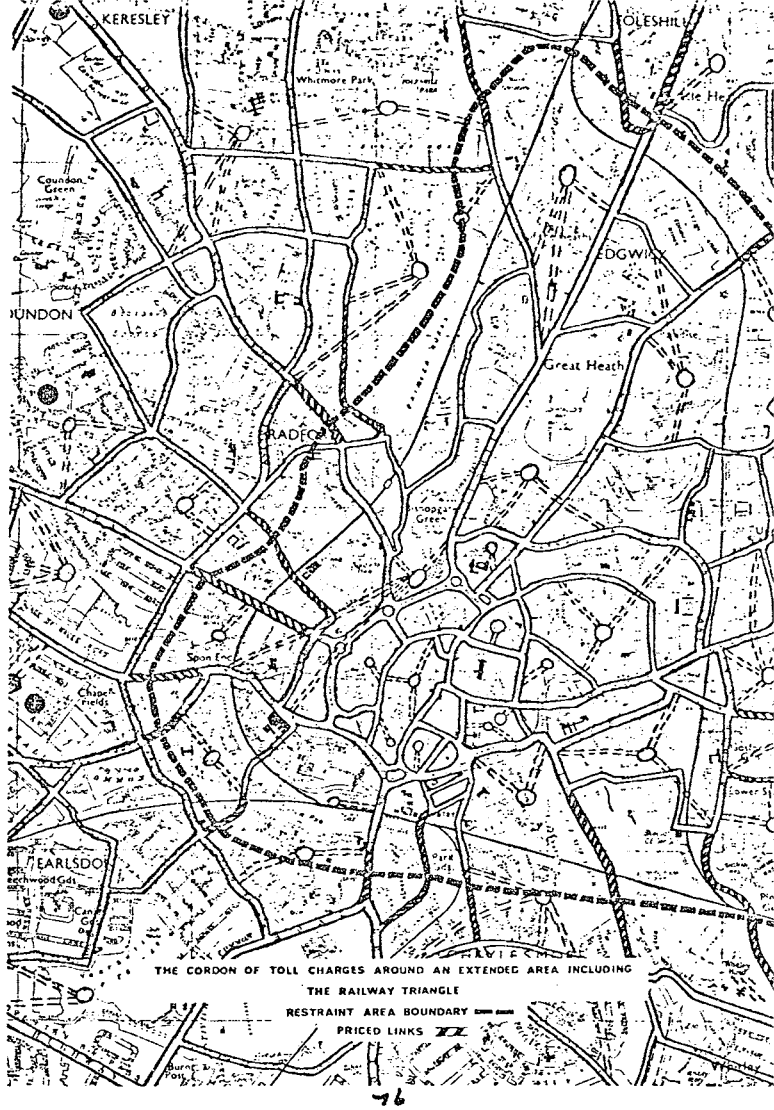

KERESLEY
OLESHILL
Whitmore Park
COUNDON
Great Heath
RADFORD
EARLSDON
THE CORDON OF TOLL CHARGE AROUND THE RAILWAY TRIANGLE
RESTRAINT AREA BOUNDARY
PRICED LINKS

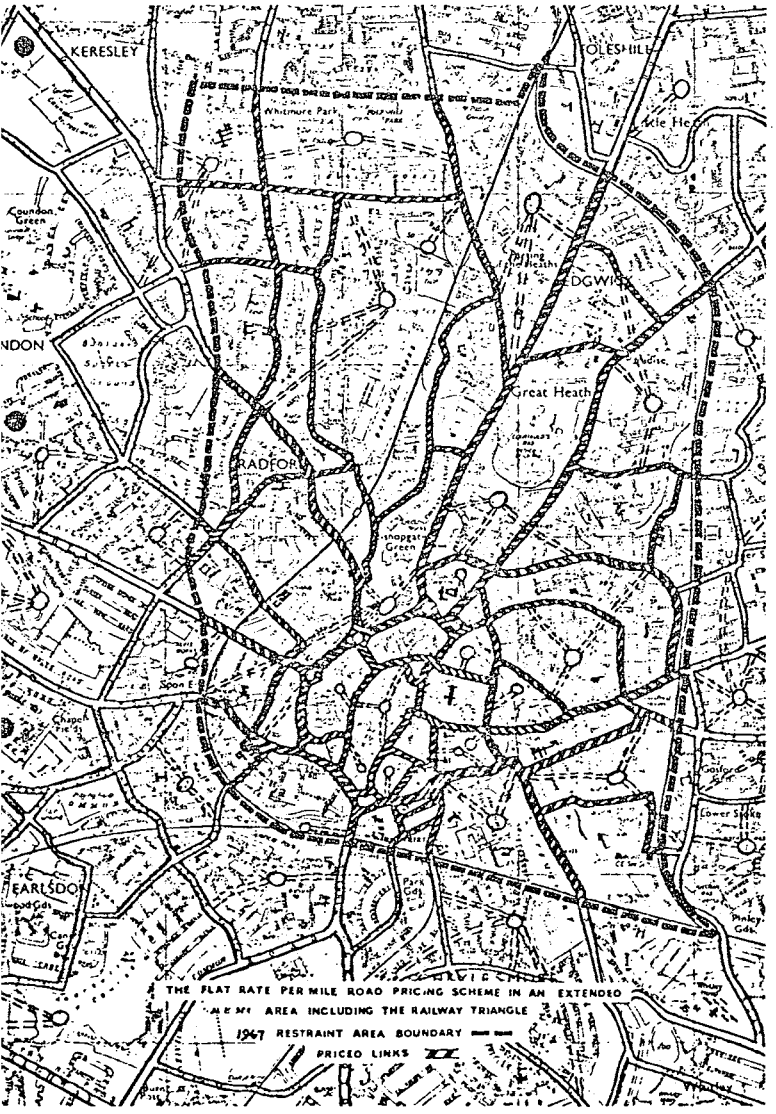
6b


Holbrooks
KERESLEY
OLESHILL
Whitmore Park
Great Heath
RADFORD
EARLSDON
THE SUPPLEMENTARY LICENCE SCHEME IN THE RAILWAY TRIANGLE
RESTRAINT AREA BOUNDARY
PRICED LINKS


KERESLEY
OLESHILL
Whitmore Park
Great Heath
RADFORD
EARLSDON
THE FLAT RATE PER MILE ROAD PRICING SCHEME IN THE RAILWAY TRIANGLE
RESTRAINT AREA BOUNDARY
PRICED LINKS


KERESLEY
TOLESHILL
Whitmore Park
Little He
Coundon Green
EDGWI
Great Heath
RADFORD
Shopper Green
Spon End
Chapel Fields
EARLSDO
Cower Stake
Pinley Gds
THE FLAT RATE PER MILE ROAD PRICING SCHEME IN THE CENTRAL AREA ONLY
1967 RESTRAINT AREA BOUNDARY
PRICED LINKS


KERESLEY
TOLESHILL
Whitmore Park
Coundon Green
EDGWI
Great Heath
RADFORD
Shopper Green
Spon End
Chapel Fields
EARLSDO
THE CORDON OF TOLL CHARGES AROUND AN EXTENDED AREA INCLUDING THE RAILWAY TRIANGLE
RESTRAINT AREA BOUNDARY
PRICED LINKS


KERESLEY
TOLESHILL
Whitmore Park
Coundon Green
EDGWI
Great Heath
RADFORD
Shopper Green
Spon End
Chapel Fields
EARLSDO
Cower Stake
Pinley Gds
THE FLAT RATE PER MILE ROAD PRICING SCHEME IN AN EXTENDED AREA INCLUDING THE RAILWAY TRIANGLE
1967 RESTRAINT AREA BOUNDARY
PRICED LINKS

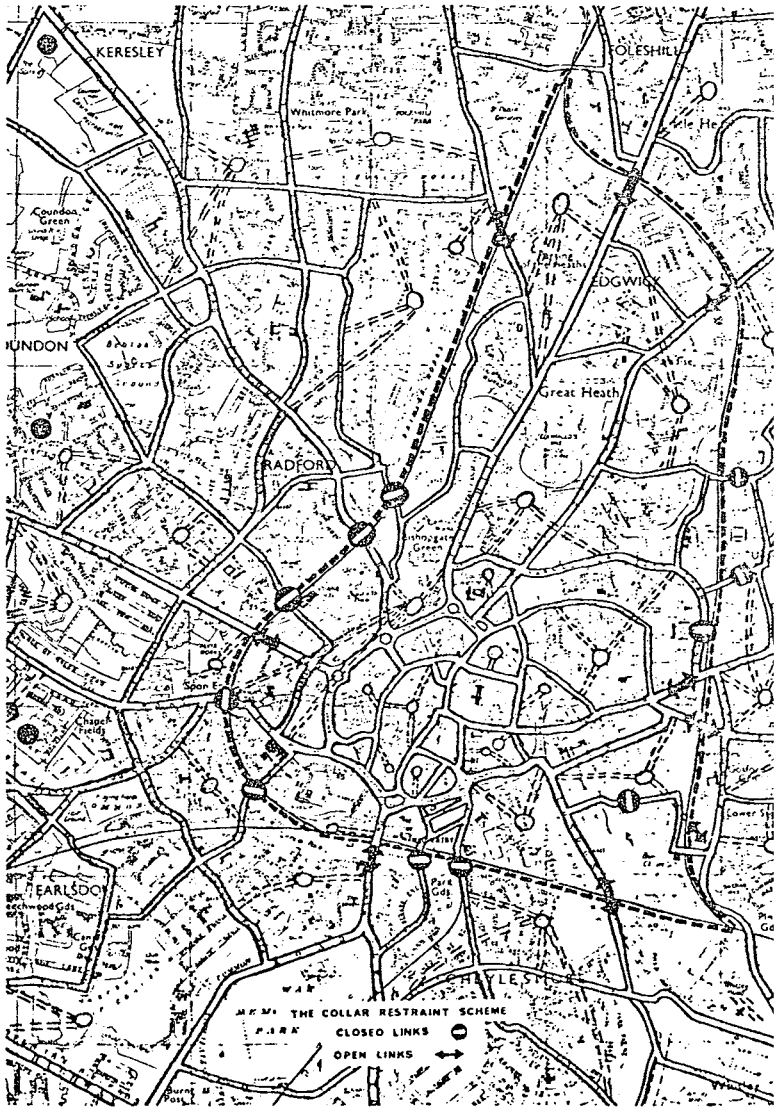
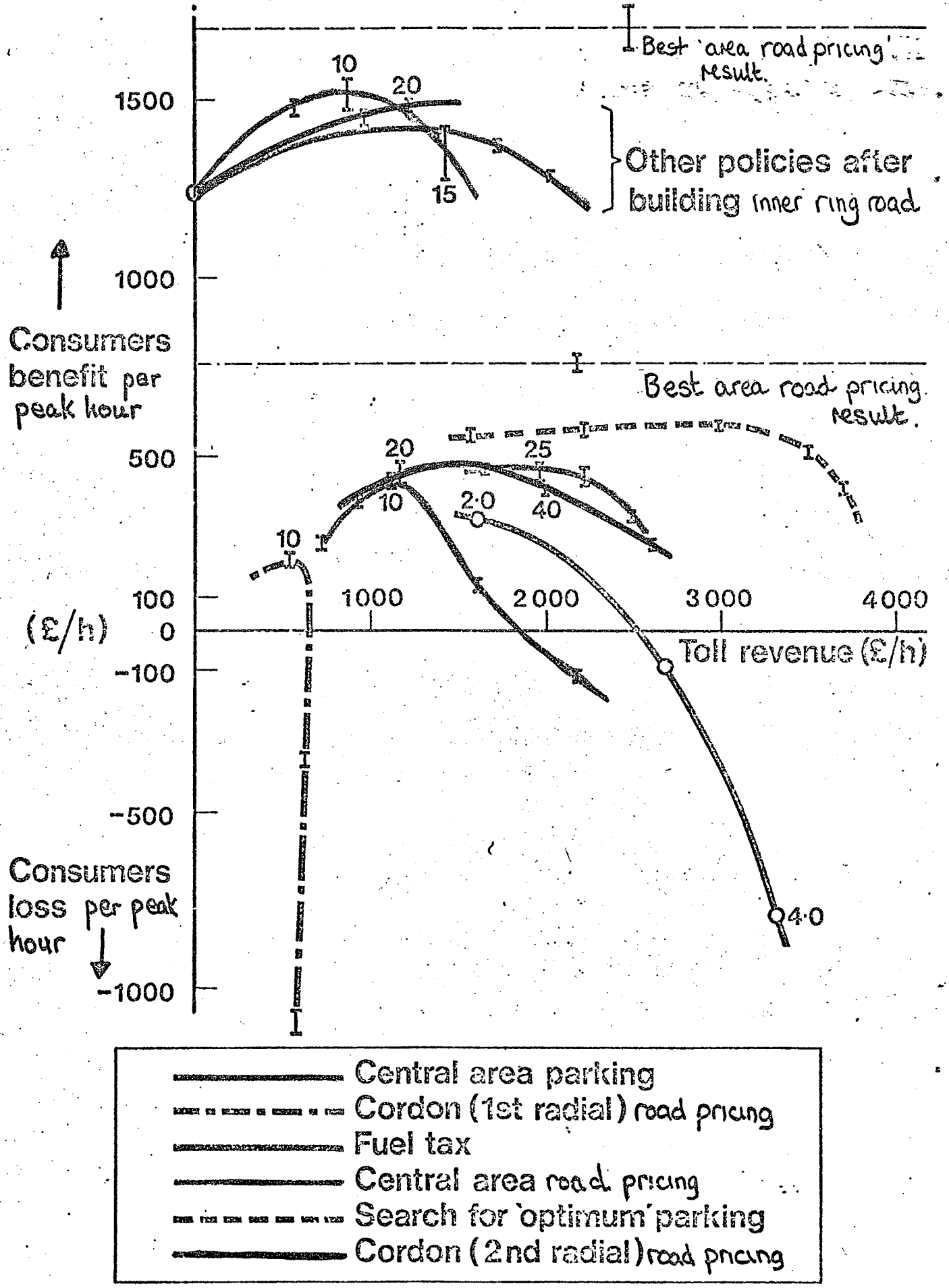

KERESLEY
TOLESHILL
Whitmore Park
Coundon Green
EDGWI
Great Heath
RADFORD
Shopper Green
Spon End
Chapel Fields
EARLSDO
THE COLLAR RESTRAINT SCHEME
CLOSED LINKS
OPEN LINKS

FIG 8: COMPARATIVE EFFECTIVENESS OF A RANGE OF RESTRAINT POLICIES ON A HYPOTHETICAL NETWORK



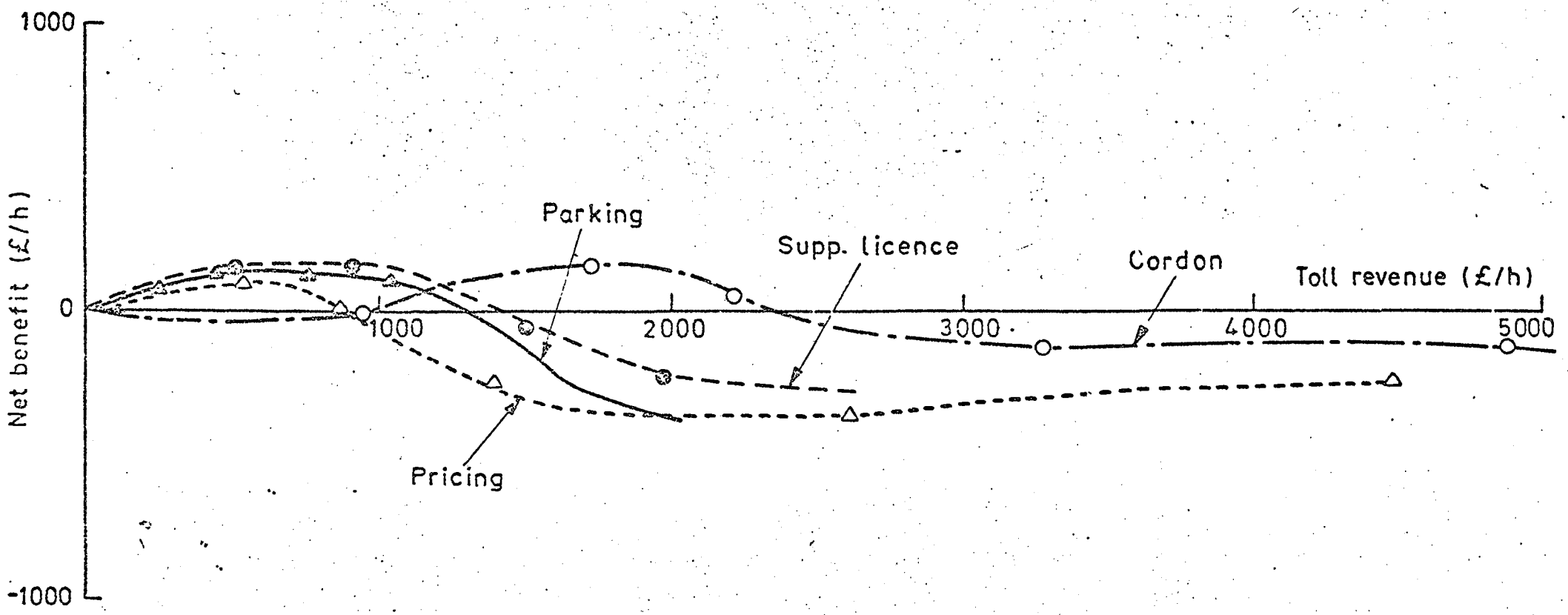


FIGURE 9 : RESTRAINTS RESTRICTED TO THE RAILWAY TRIANGLE

G 5956

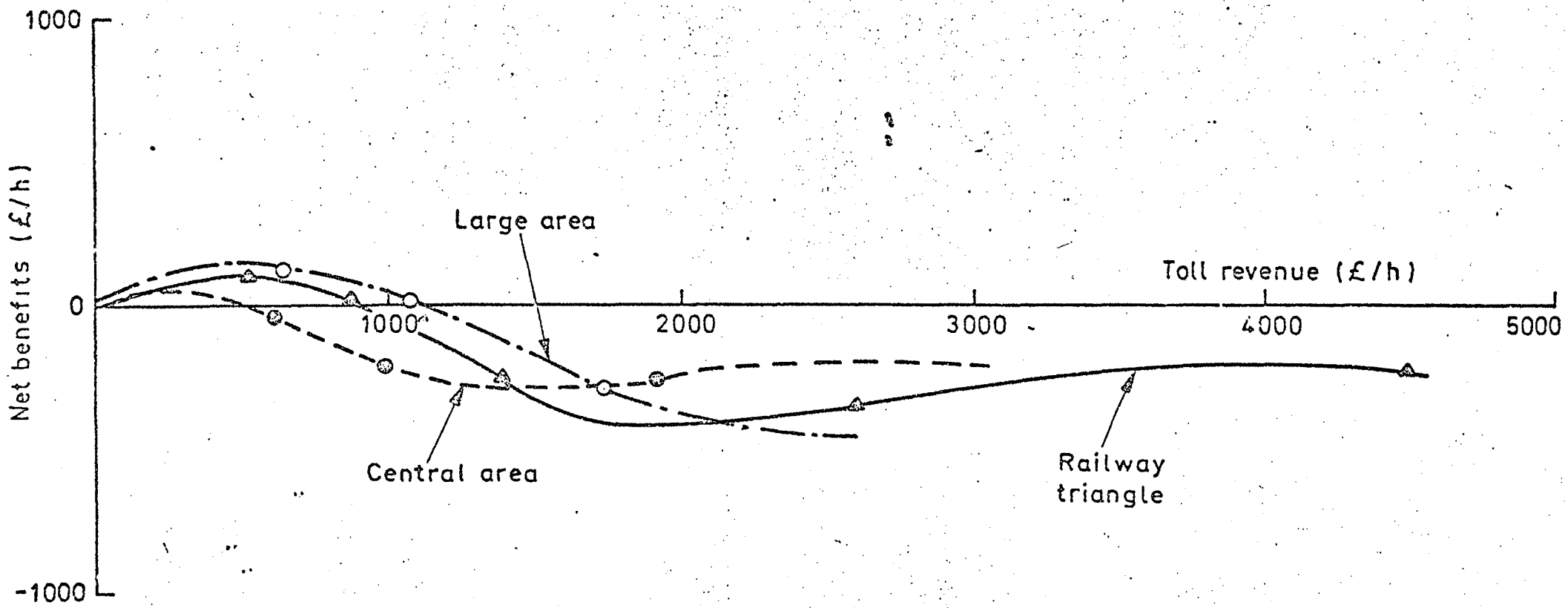
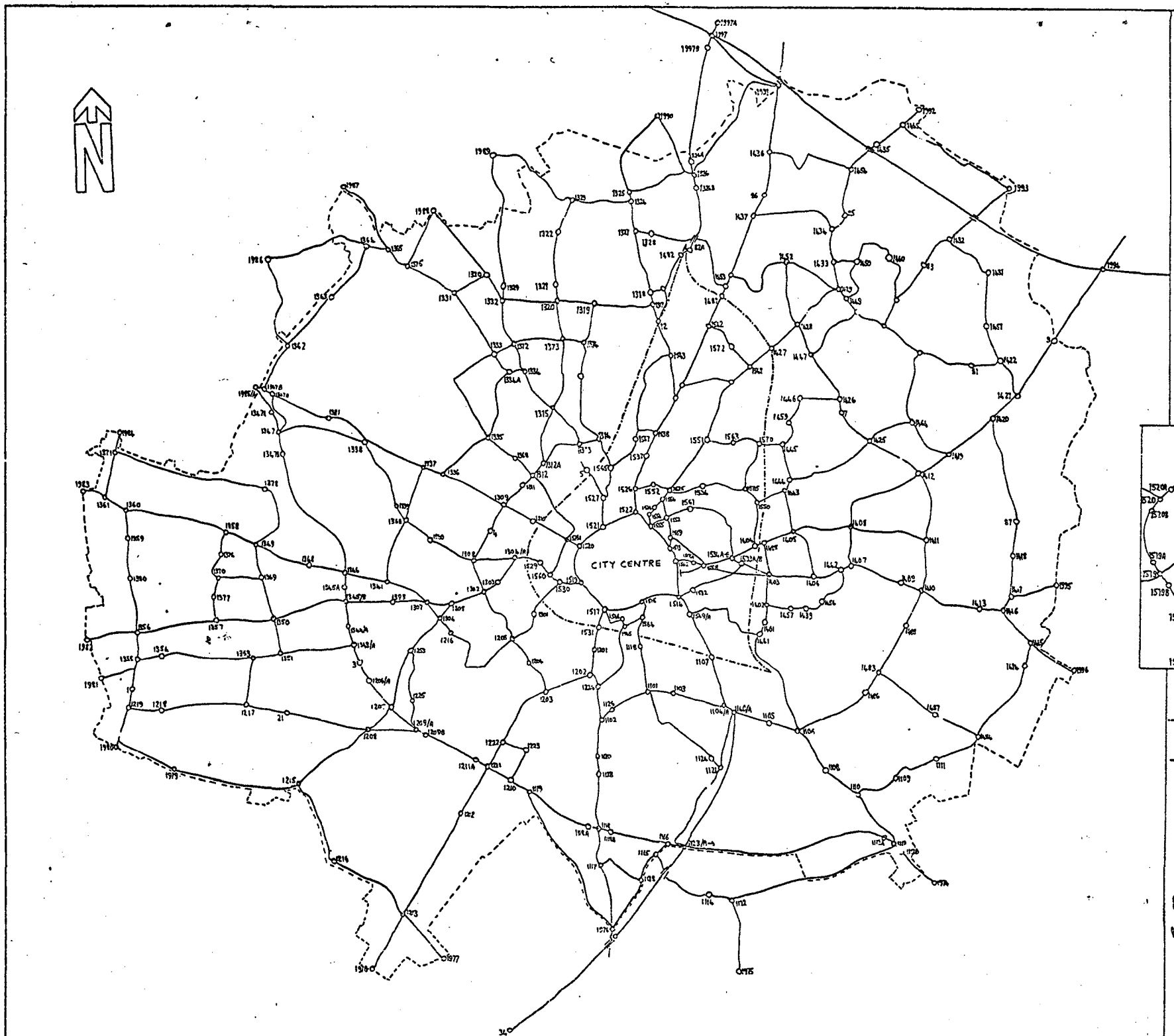


FIGURE 10: AREA ROAD PRICING APPLIED TO DIFFERENT SIZES OF RESTRAINT DISTRICT

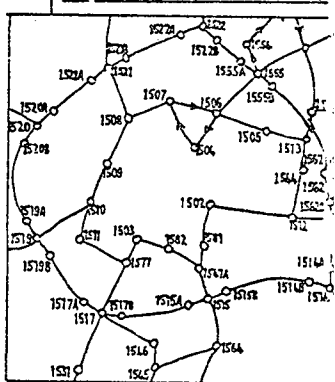
COVENTRY

1981 HIGHWAY NETWORK

TRRL SCENARIO



(INSET) CITY CENTRE



—·—·— RAILWAY TRIANGLE

— — — CITY BOUNDARY

FIGURE 11

ROAD NETWORK USED FOR '1981' SCENARIOS.

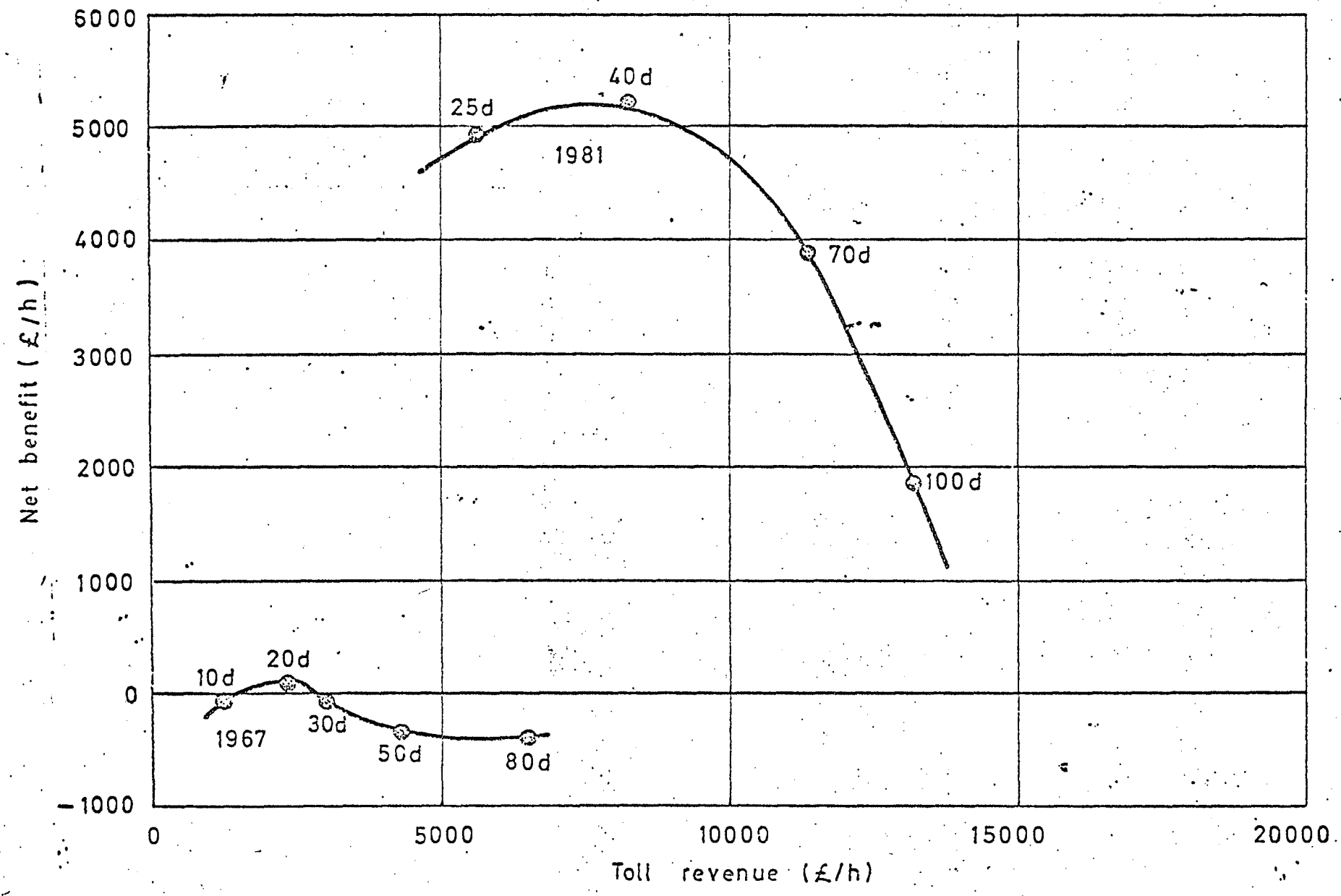


Fig. 12 COVENTRY CORDON RESTRAINT RAILWAY TRIANGLE BENEFIT-REVENUE CURVES IN 1970 £s

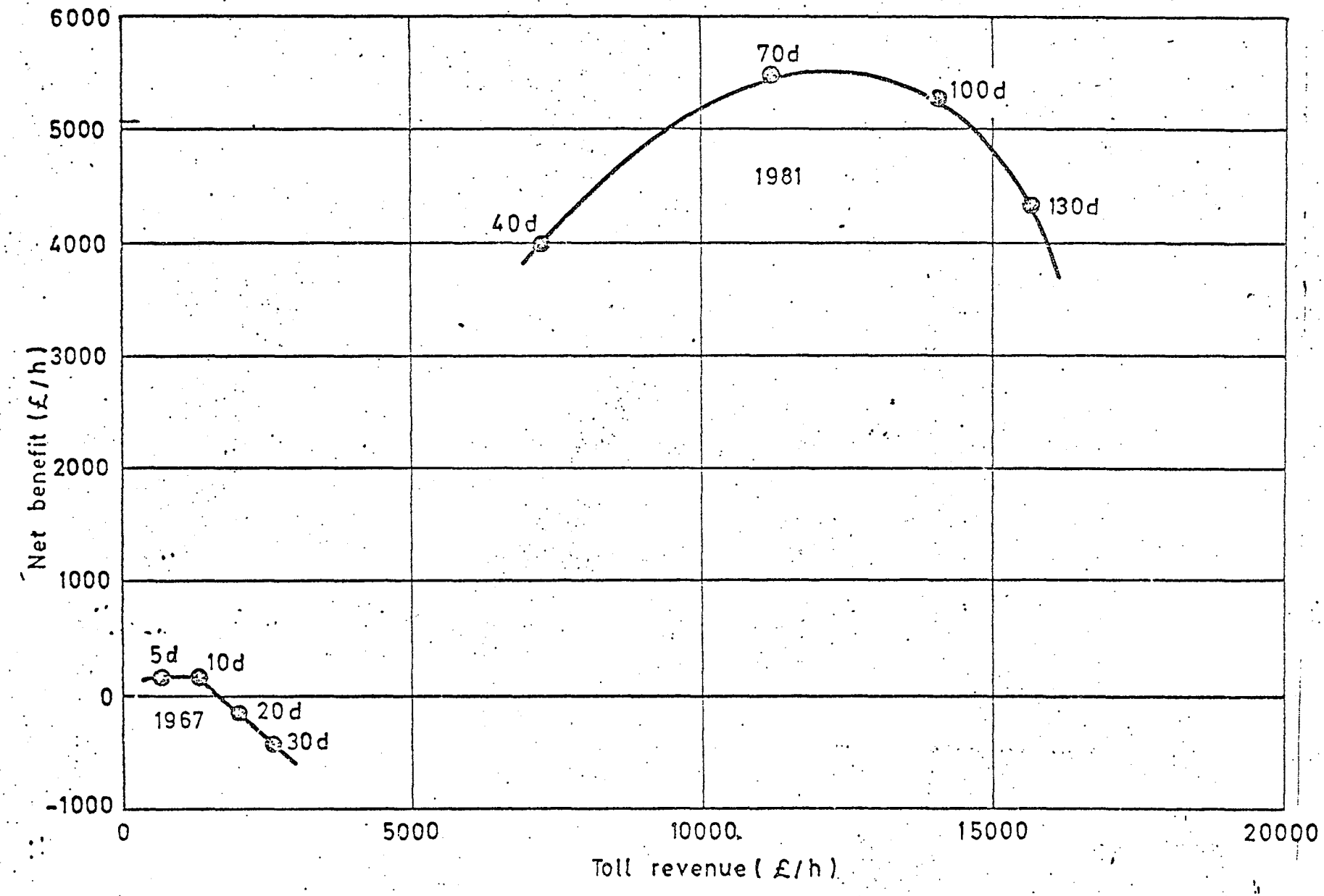


Fig. 13 COVENTRY SUPPLEMENTARY LICENCE RESTRAINT RAILWAY TRIANGLE BENEFIT - REVENUE CURVES 1970 £s

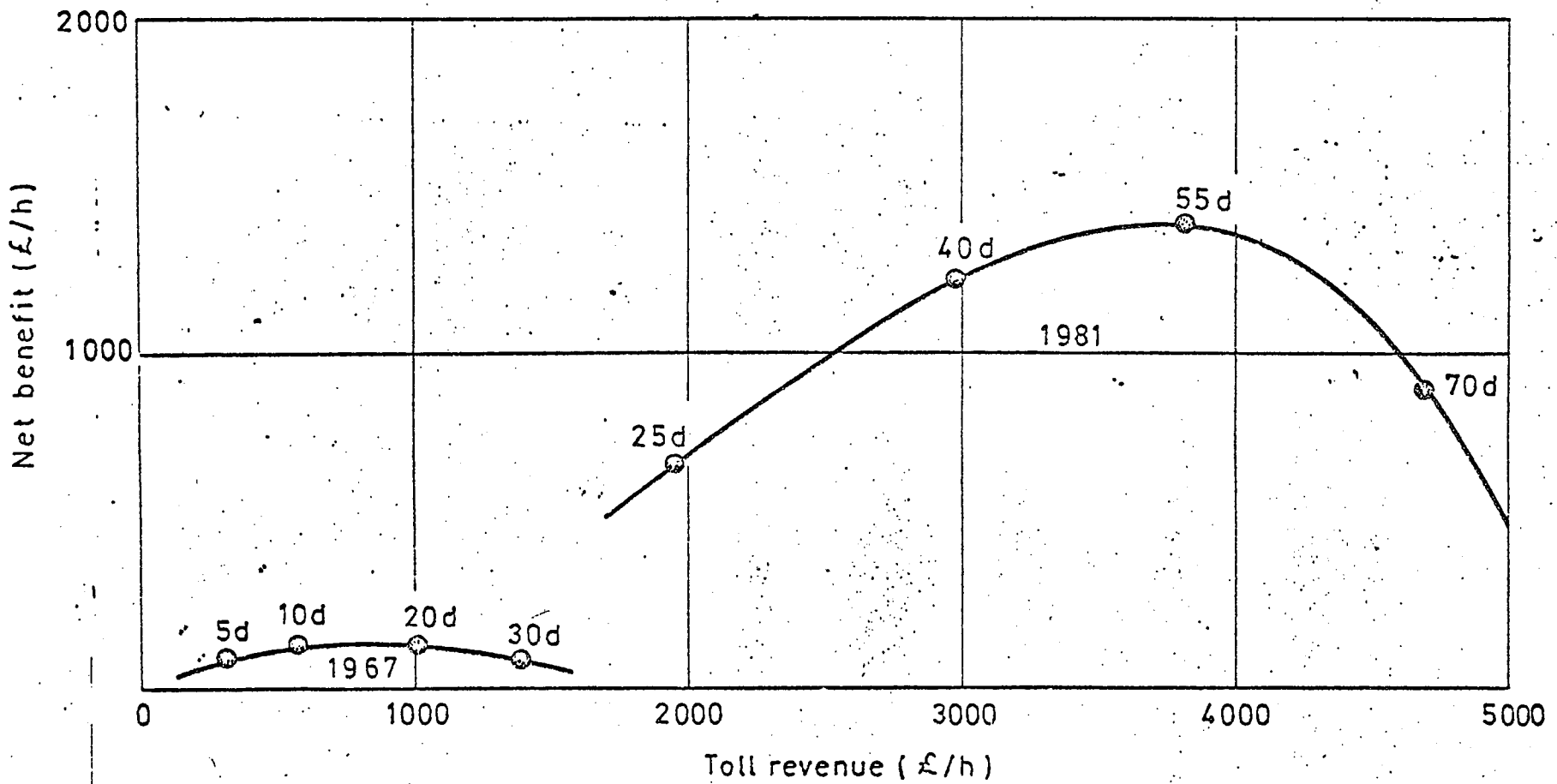


Fig. 14 COVENTRY PARKING RESTRAINT RAILWAY TRIANGLE
BENEFIT-REVENUE CURVES 1970 £s

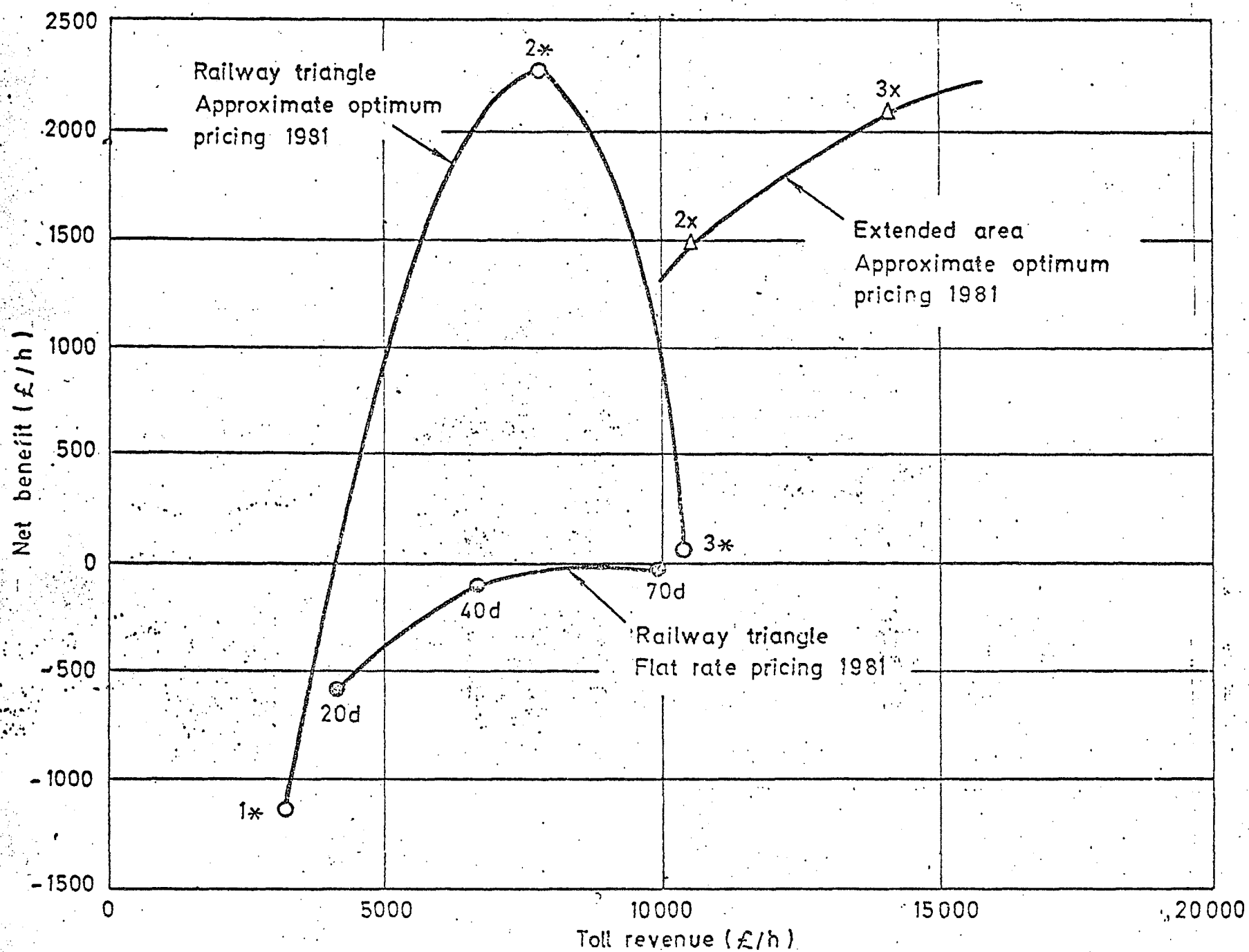


Fig.16 PRICING POINT RESTRAINT SCHEMES – COVENTRY

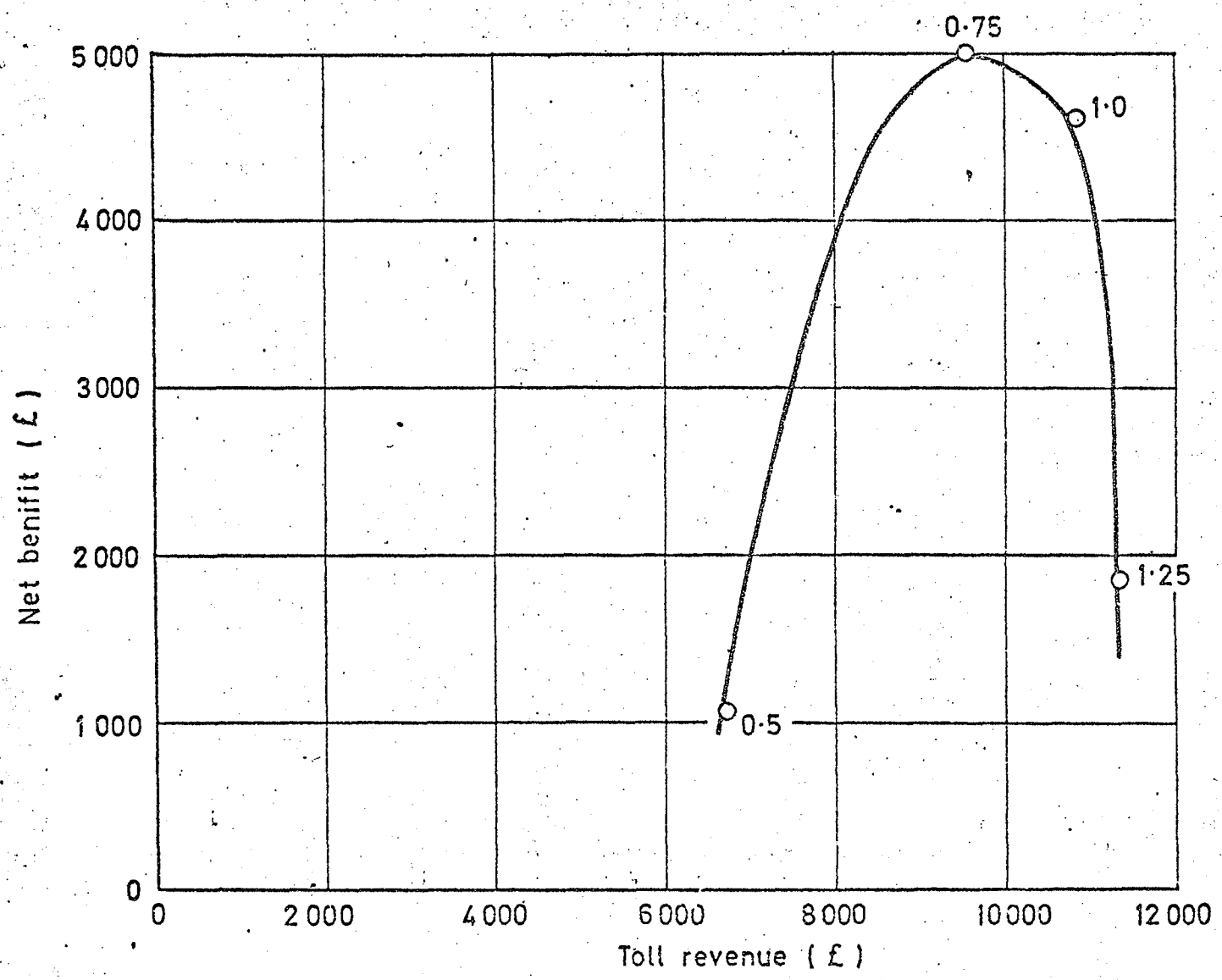


FIGURE 16 :- COVENTRY 1981

OPTIMUM PRICING - EQUAL TOLLS SET ON HIGHER AMOUNT FOR EACH LINK. FACTORS SHOWN ARE BASED ON TSW 38 RUN PREDICTIONS

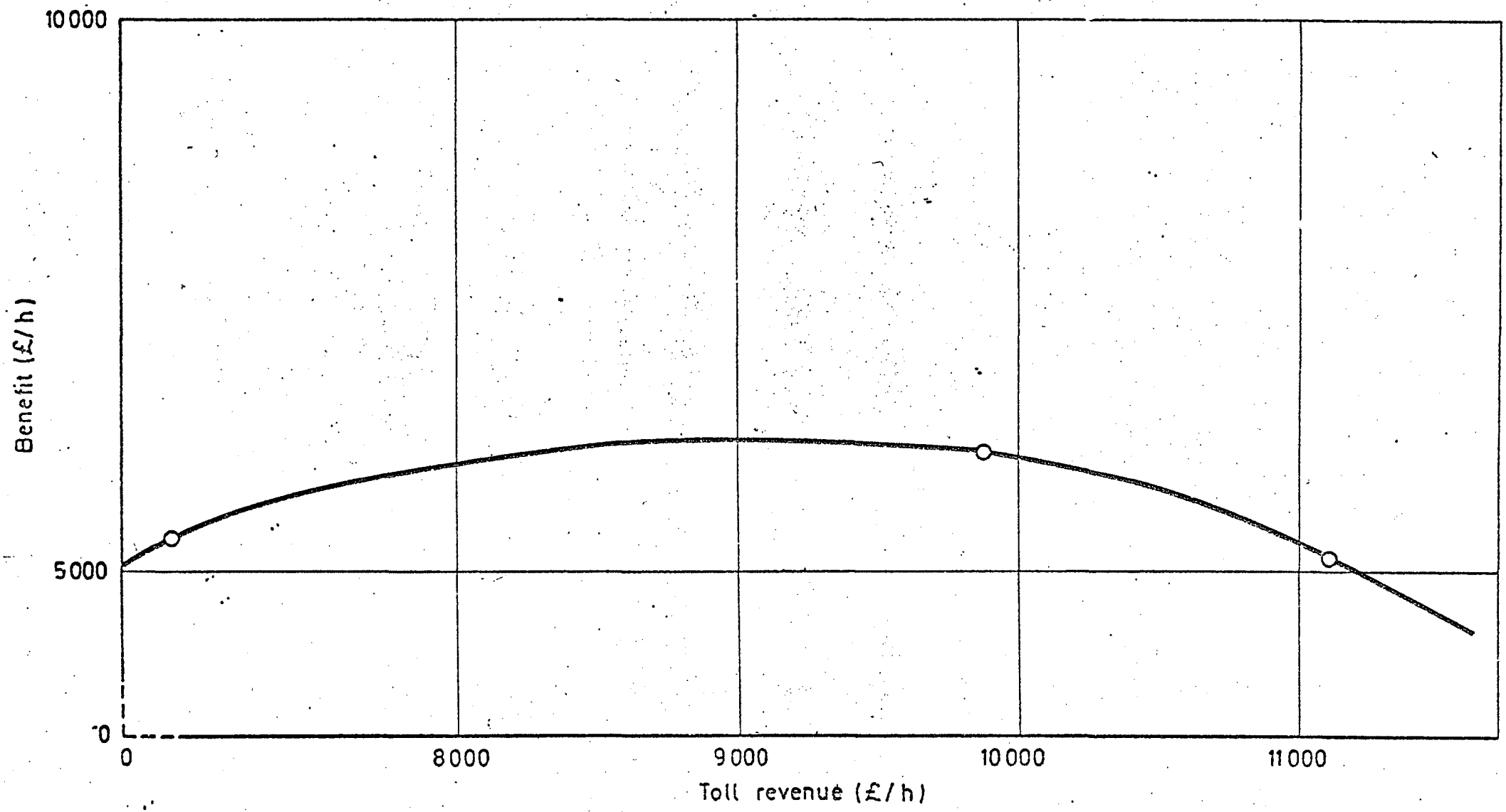


FIGURE 17 : CORDON OUTWARD ONLY (EXCL. BUS)

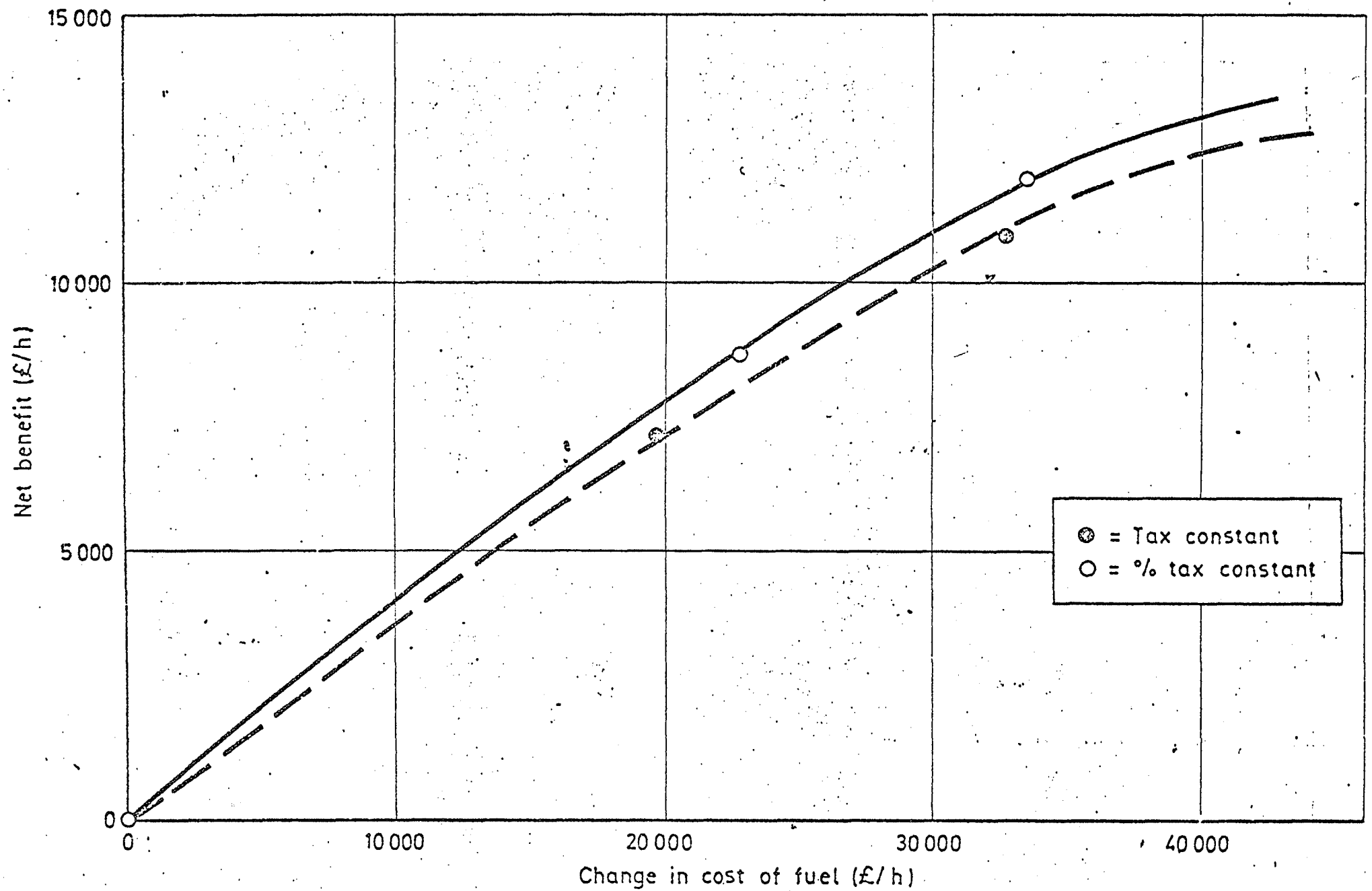


FIGURE 18 : FUEL COSTS

SUPPLEMENTARY LICENCE AND PARKING POINTS
and resulting goods and private benefits(£)

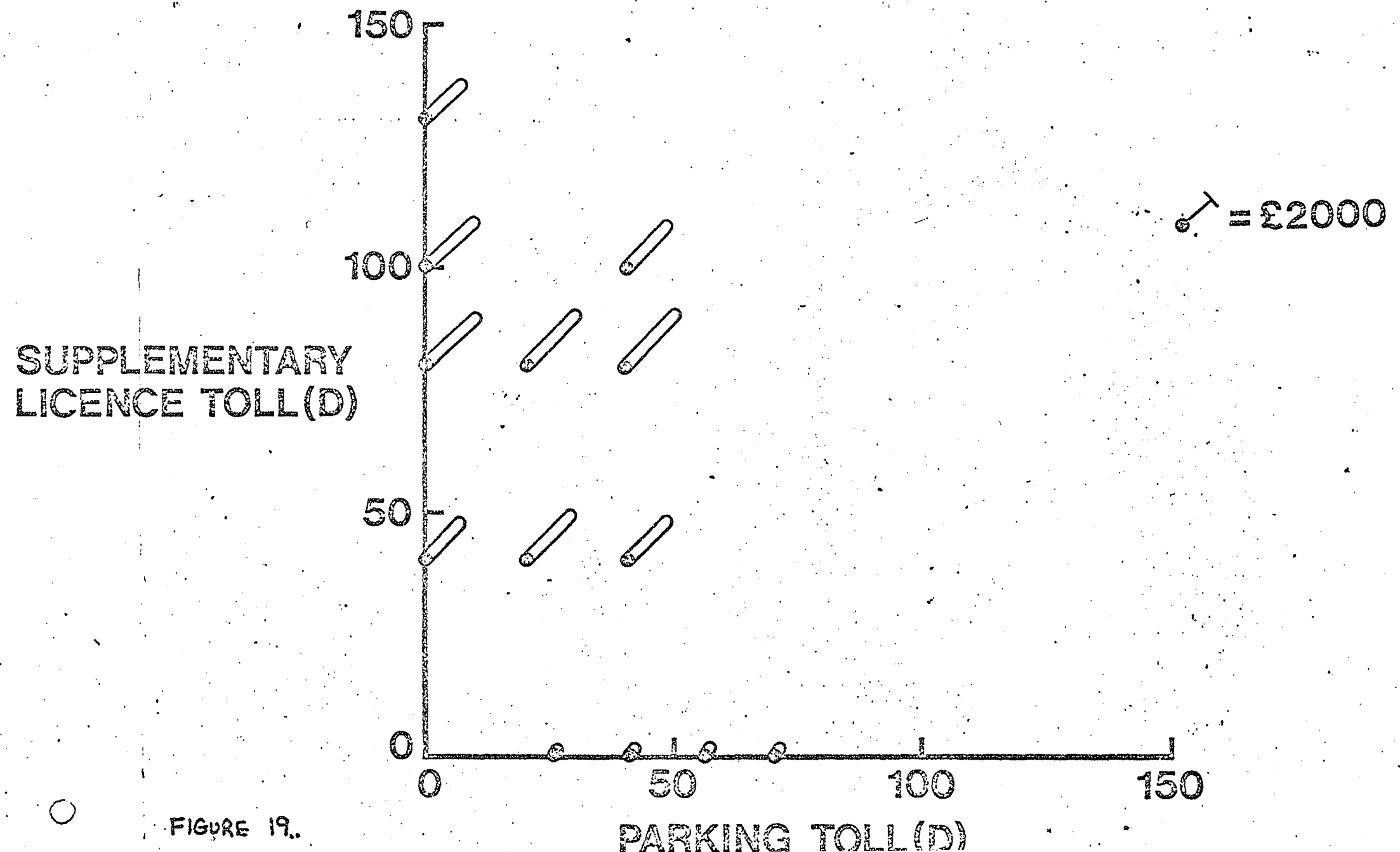


FIGURE 19.

CORDON AND PARKING POINTS
and resulting goods and private benefits(c)

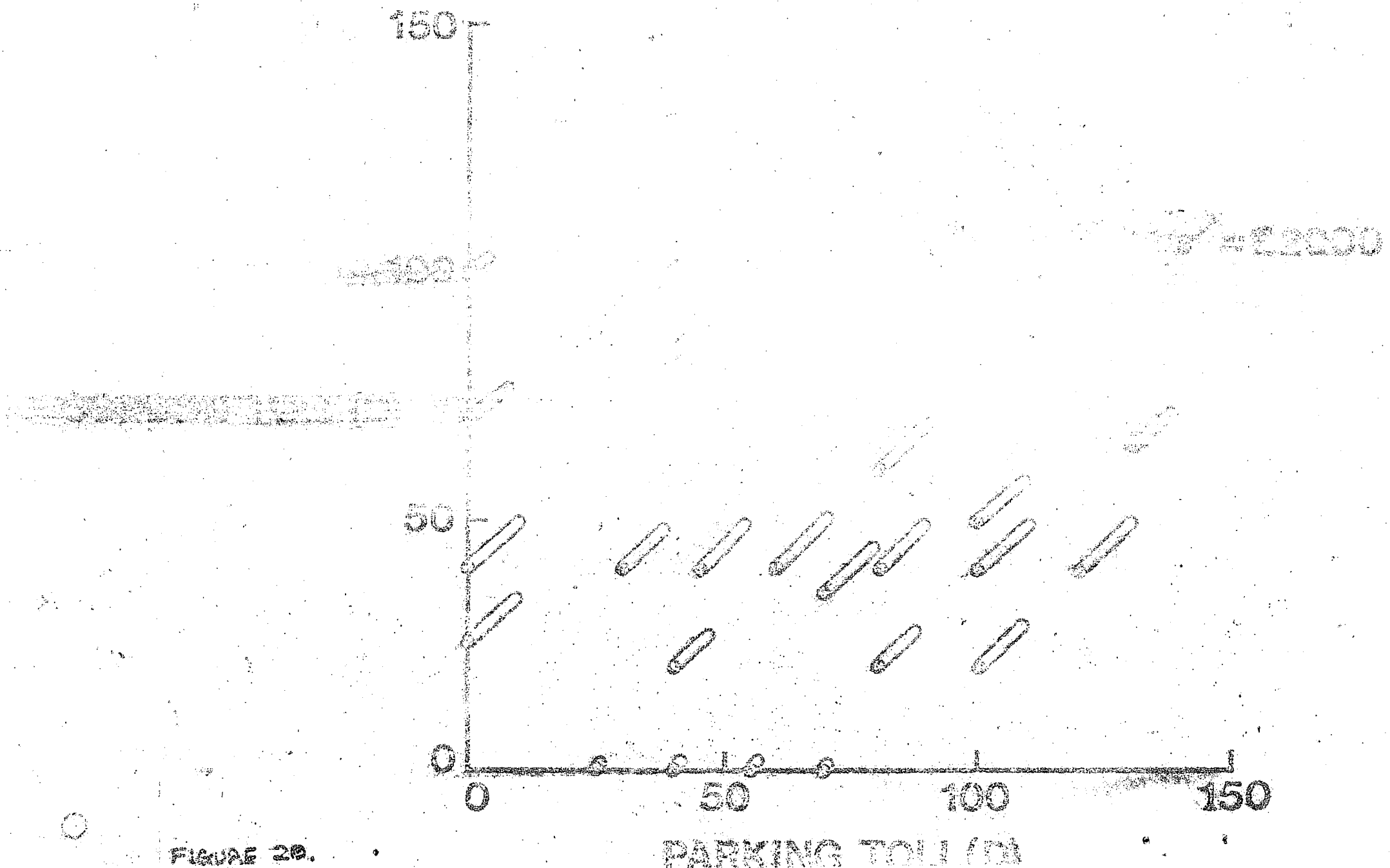


FIGURE 29.

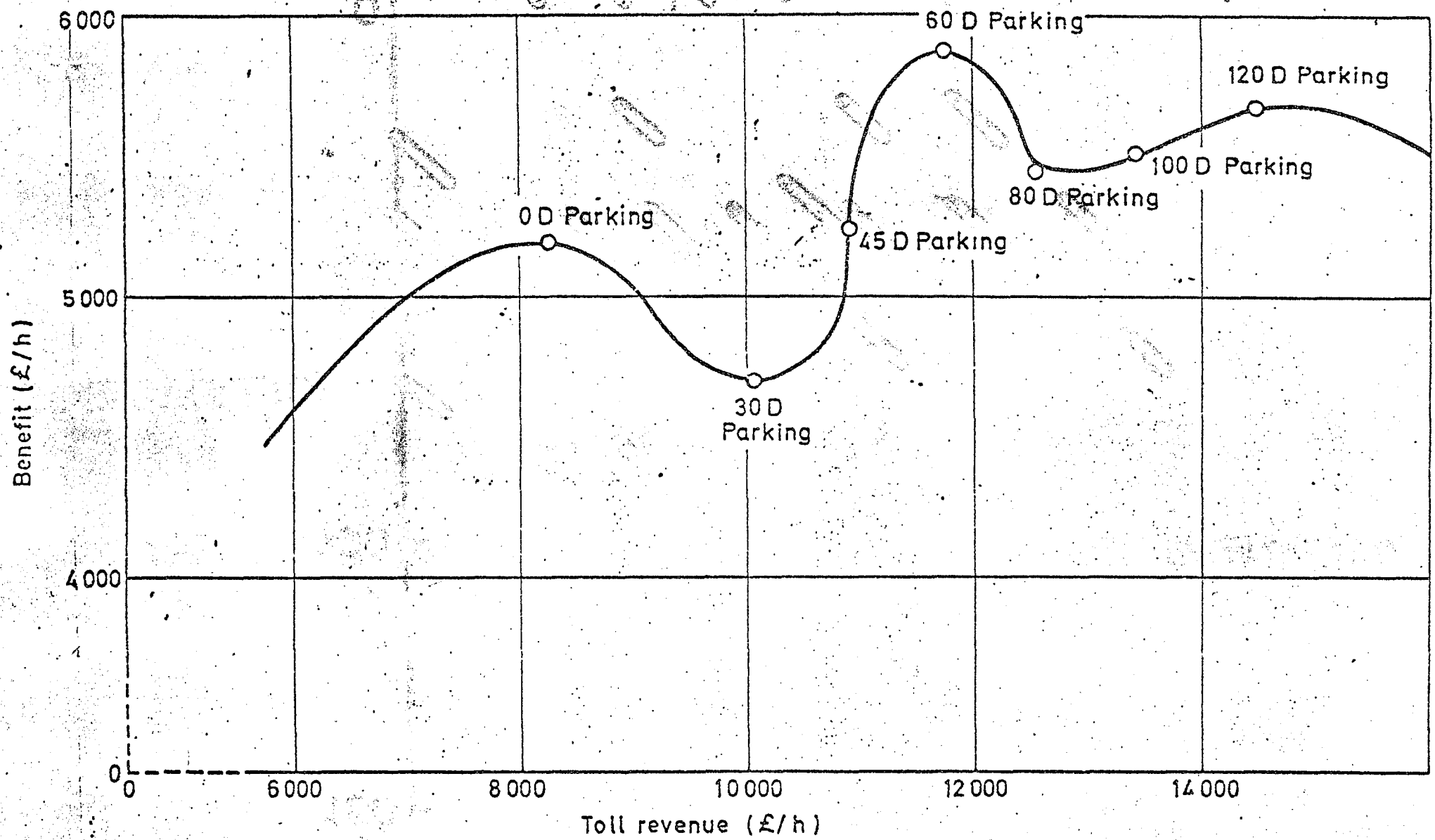


FIGURE 21: CORDON 40D AND PARKING

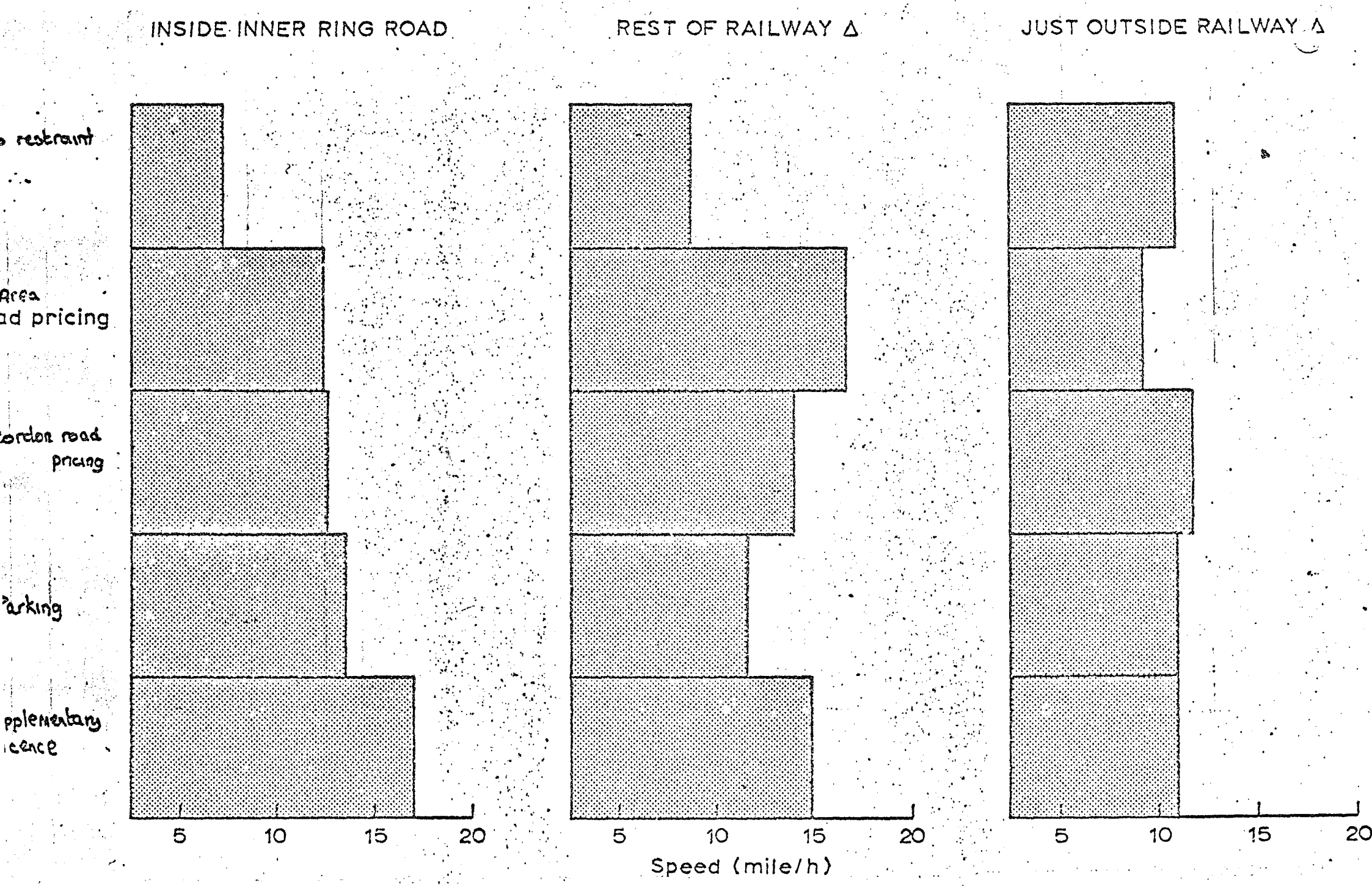


FIGURE 22: EFFECT OF RESTRAINT ON AVERAGE SPEEDS

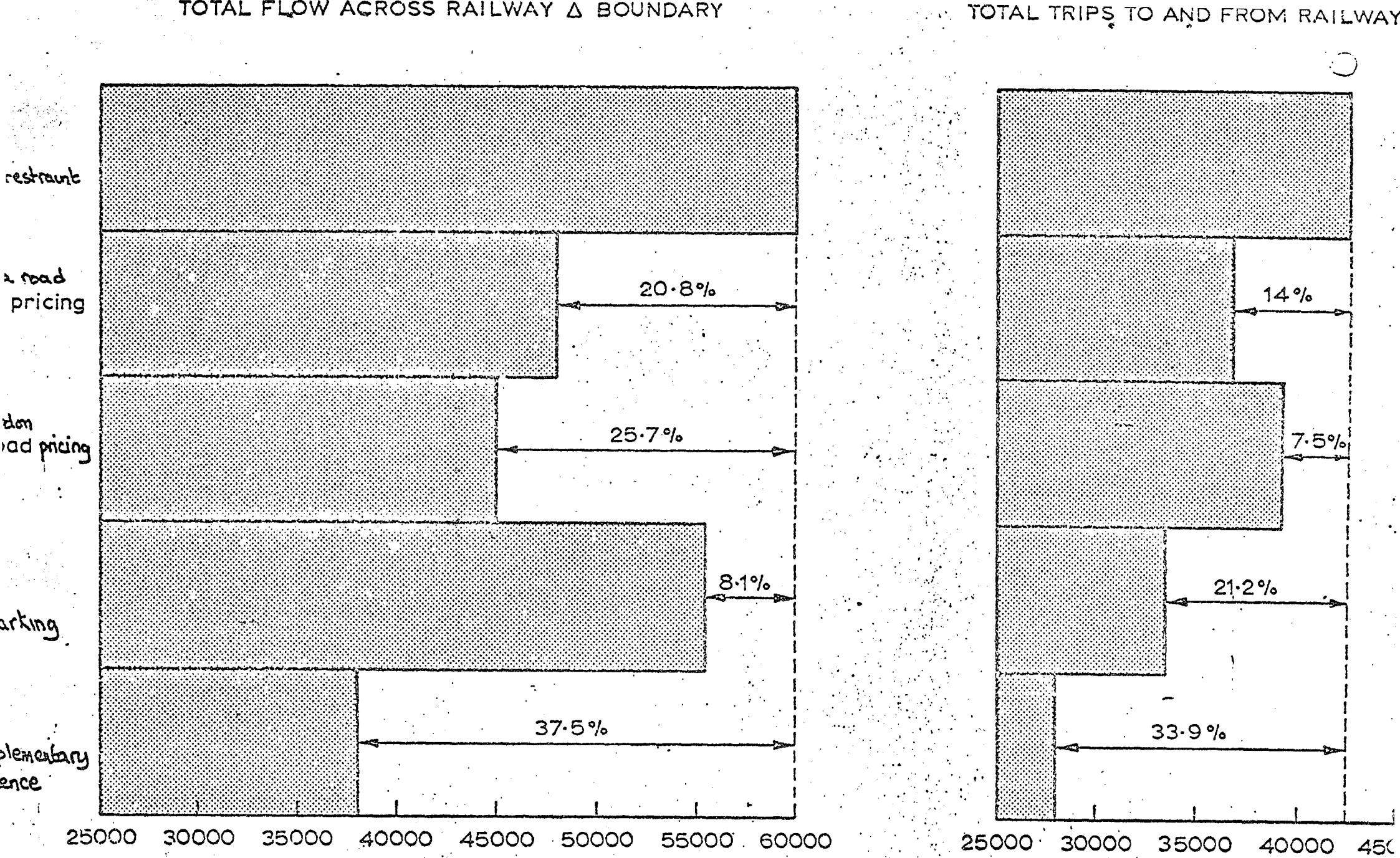
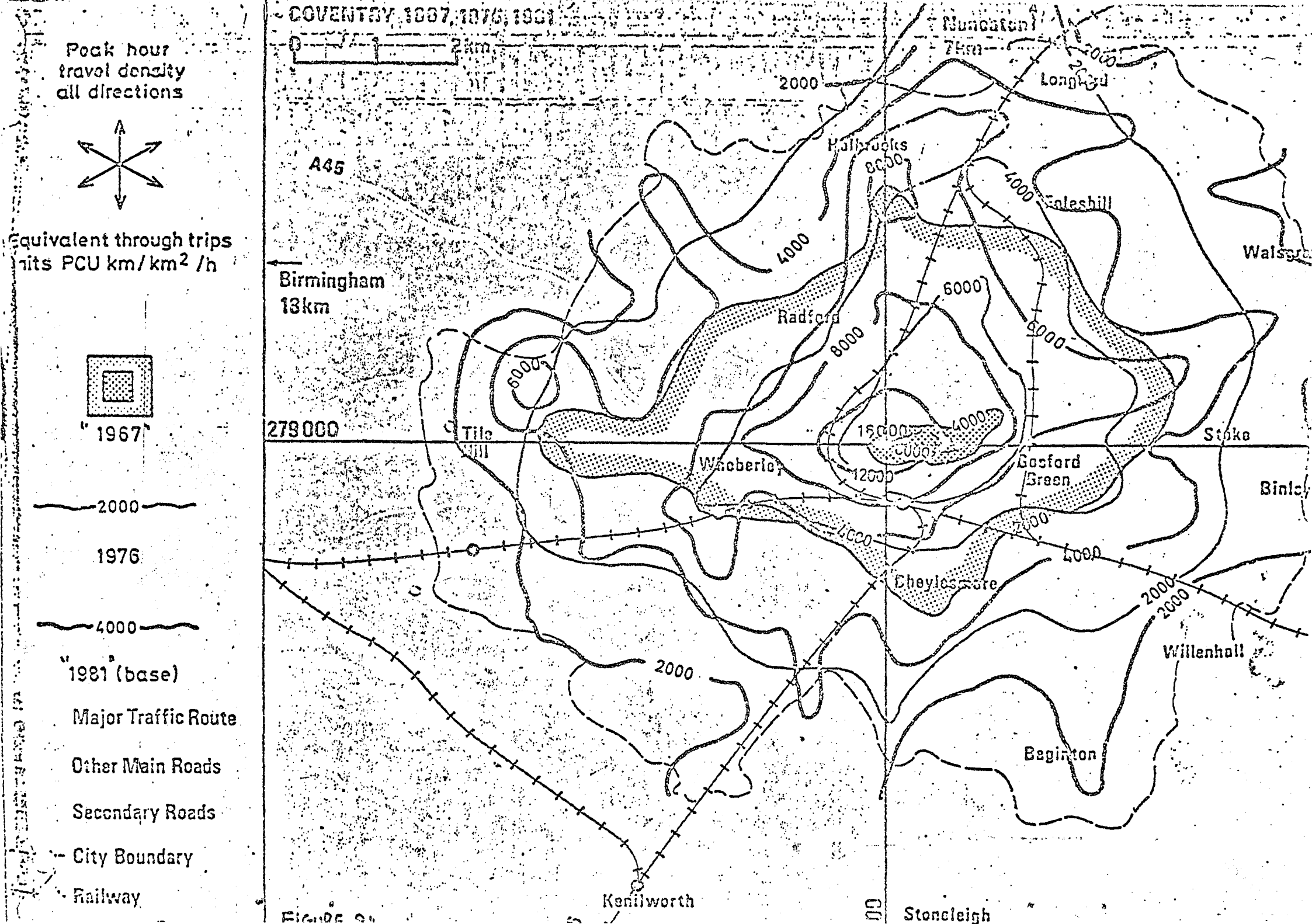
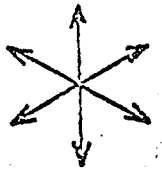


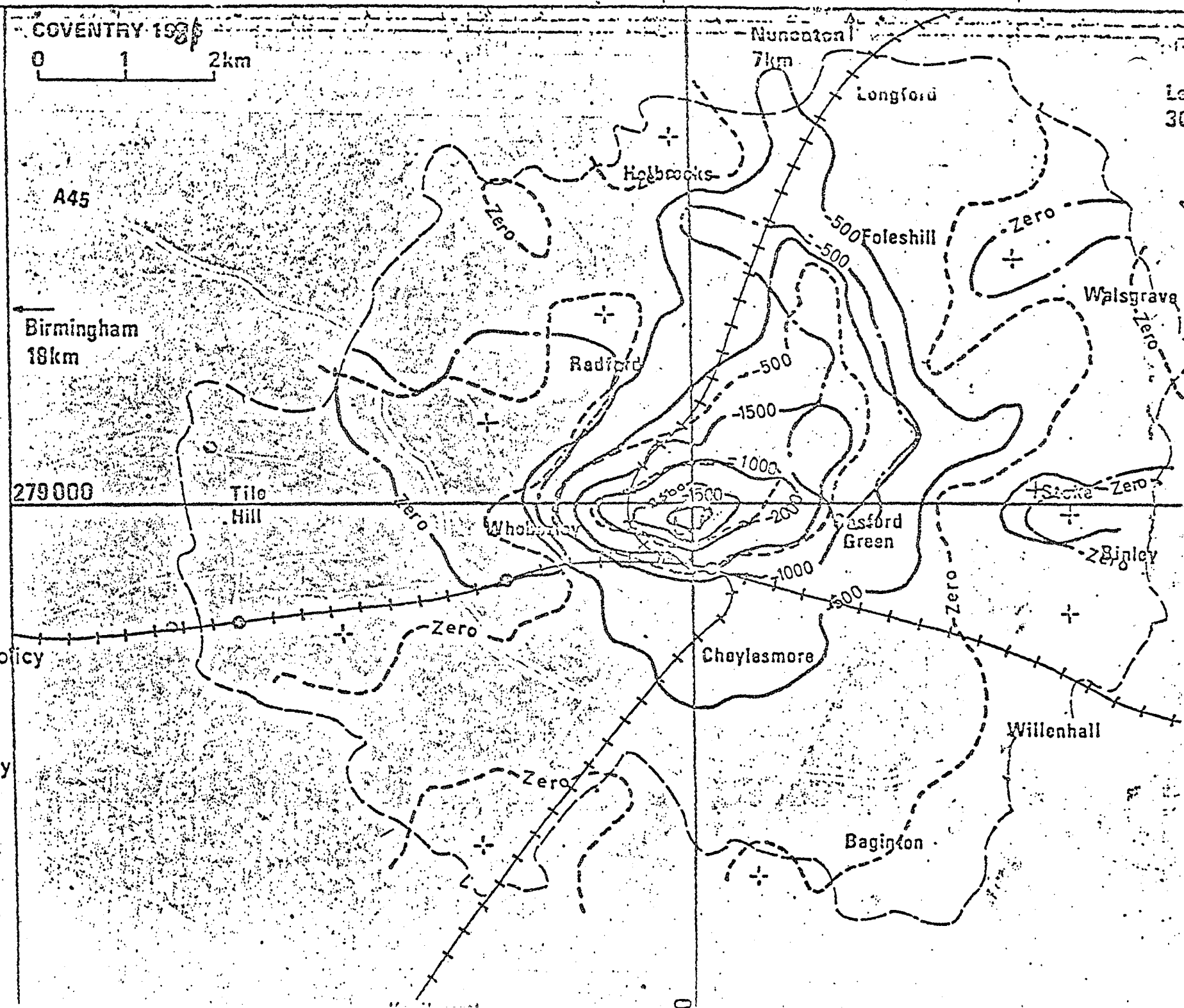
FIGURE 23 : TRAFFIC RESTRAINT IN COVENTRY 1981


COVENTRY 1967, 1976, 1981
0
2km
Peak hour travel density all directions
Equivalent through trips units PCU km/km² /h
"1967"
2000
1976
4000
"1981" (base)
Major Traffic Route
Other Main Roads
Secondary Roads
City Boundary
Railway
Birmingham 13km
A45
Nuneaton
7km
Longford
Hollyfocks
Foleshill
Walsgrave
Radford
Tile Hill
Whoberley
Gosford Green
Stoke
Binley
Cheylesmore
Willenhall
Bagington
Kenilworth
Stoneleigh
279000
2000
4000
6000
8000
12000
16000

Changes from base strategy movement in all directions



Isopleth interval 500 PCU km/km²/h



Cordon charging policy

Supplementary licencing policy

Parking fees policy

Major Traffic Route

Other Main Roads

Secondary Roads

City Boundary

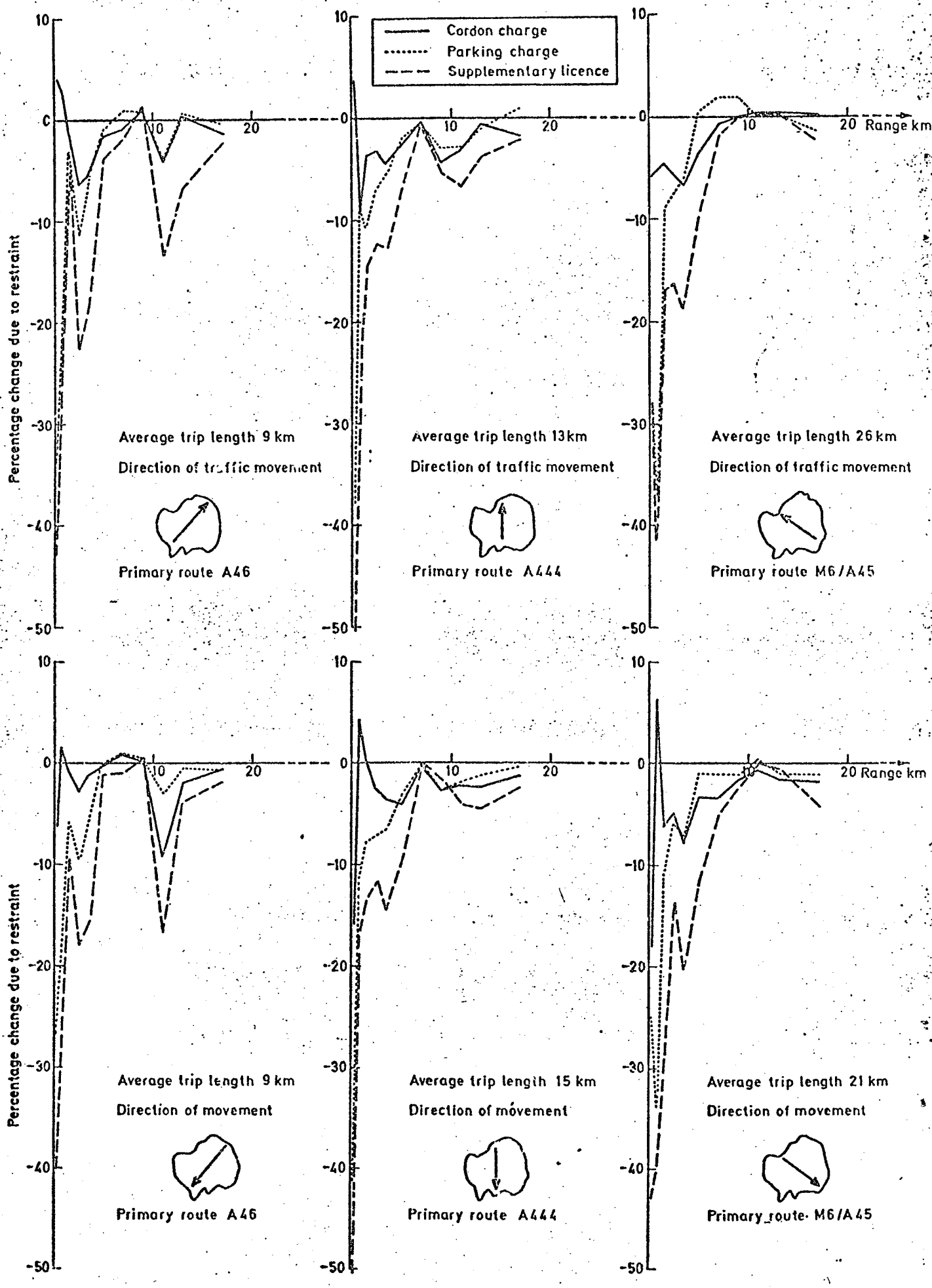
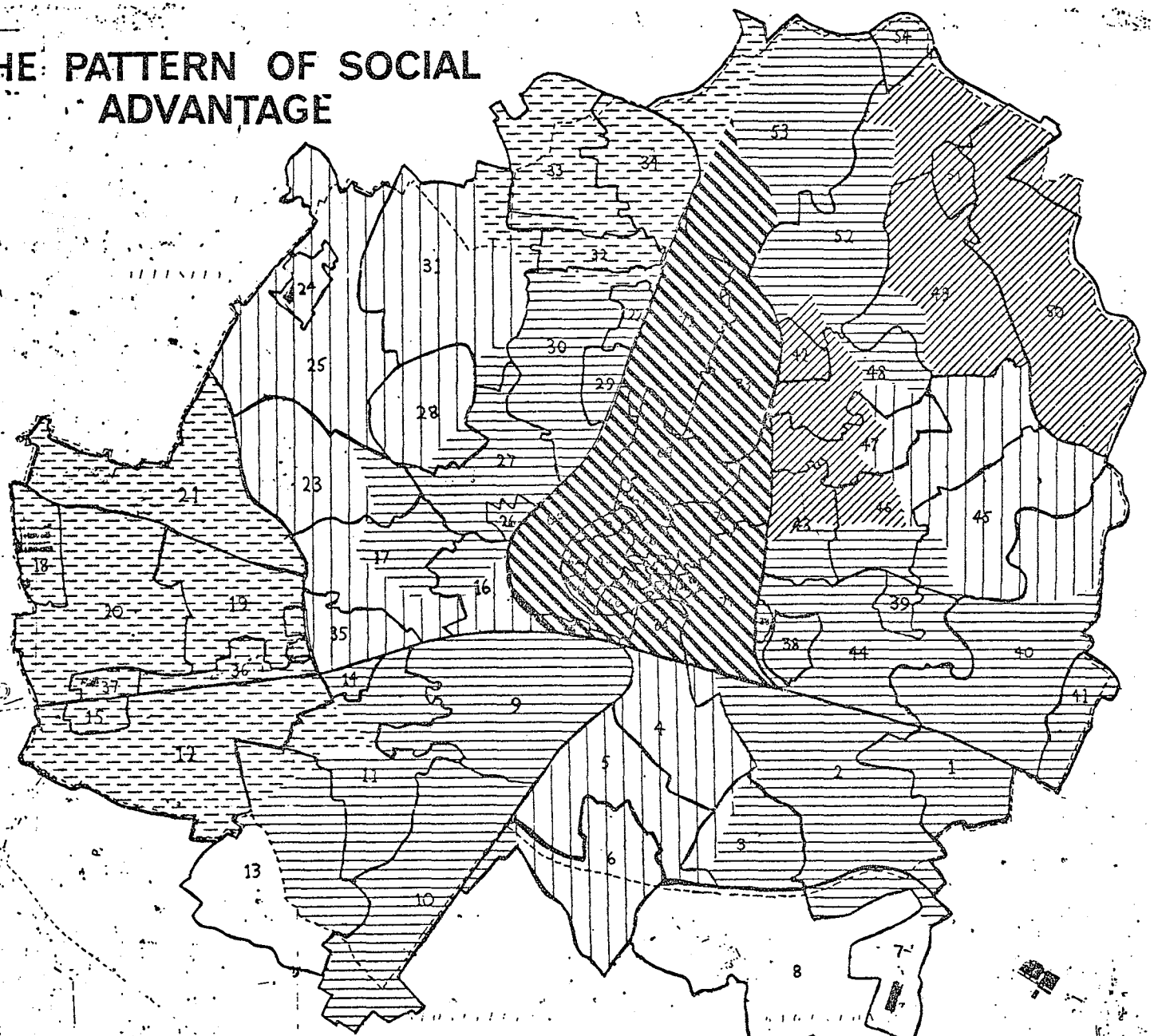


FIG 26: EFFECT OF RESTRAINT ON 1981 TRIP LENGTH DISTRIBUTIONS BY DESIRE LINE MAPPING

G5558

THE PATTERN OF SOCIAL ADVANTAGE



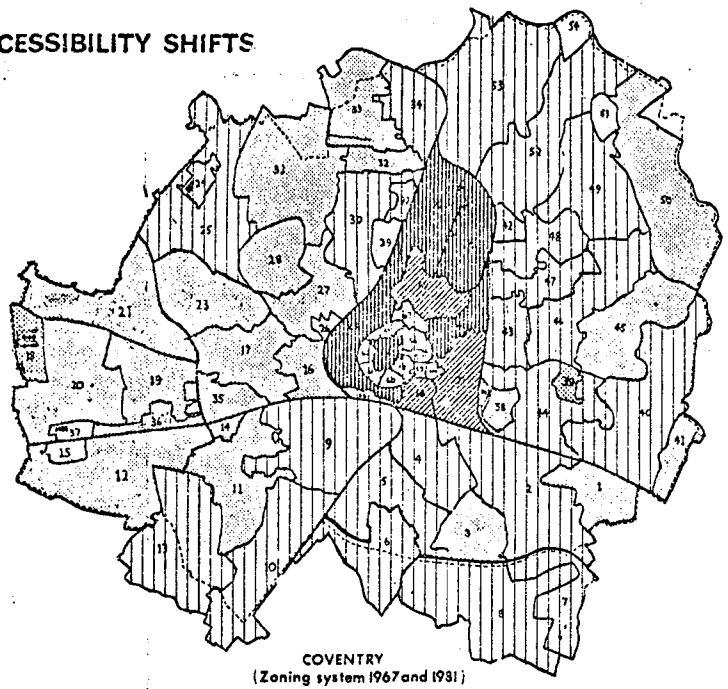
COVENTRY
(Zoning system 1967 and 1981)

SOCIAL INDICATORS

POINTS AGAINST

- 79,76,67.
- 33,32.
- 12, 12, 11, 10, 9, 9,
- 6,5,3.
- 0,0,0,0.

ACCESSIBILITY SHIFTS

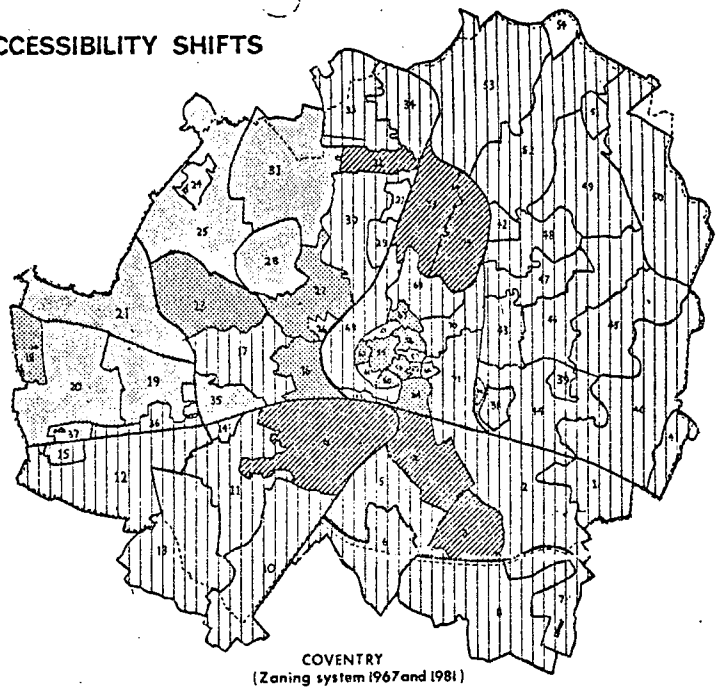


COVENTRY
(Zoning system 1967 and 1981)

PARKING (55D)
TRIP DIFFERENCES

-576	-285
-196	-179
-73	-1
+1	+39
+59	+91

ACCESSIBILITY SHIFTS

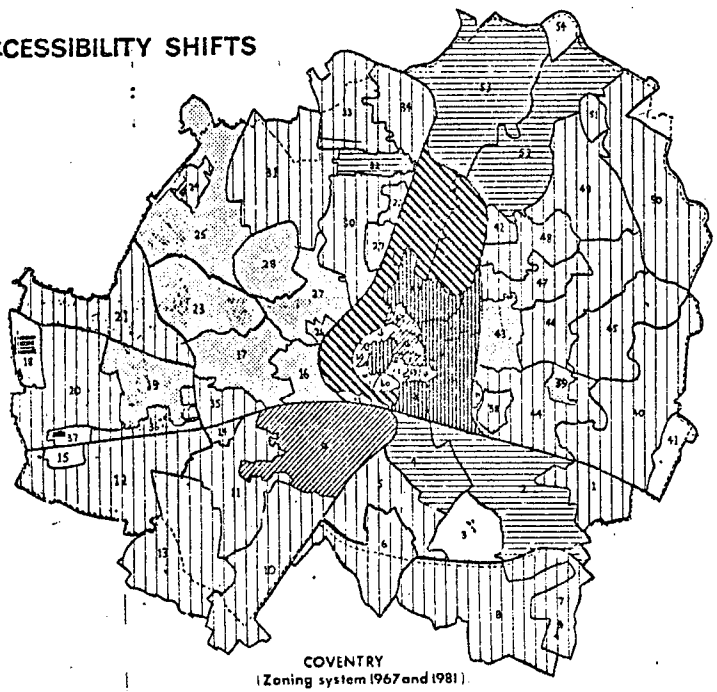


COVENTRY
(Zoning system 1967 and 1981)

CORDON (40D)
TRIP DIFFERENCES

-269	-82
-64	-1
+1	+18
+22	+118

ACCESSIBILITY SHIFTS

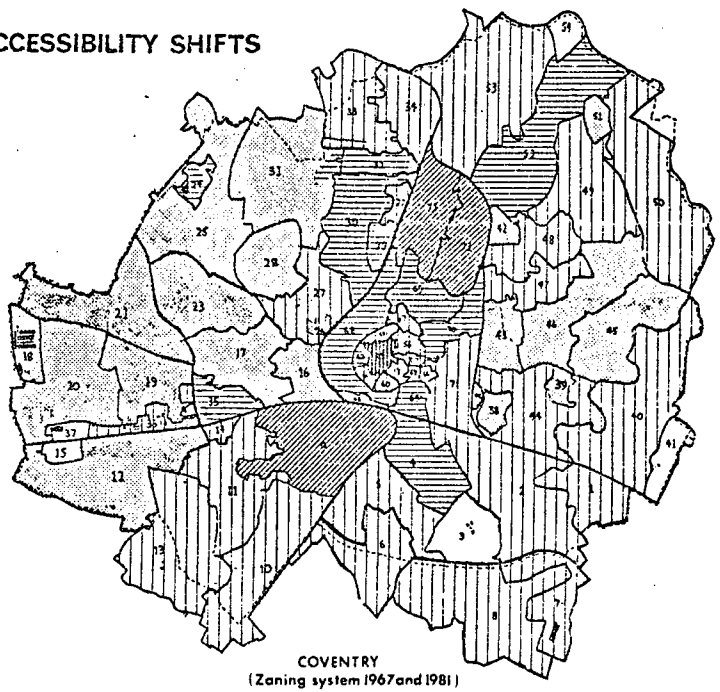


COVENTRY
(Zoning system 1967 and 1981)

SUPPLEMENTARY LICENCING (100D)
TRIP DIFFERENCES

-1015	-921
-684	-319
-174	-122
-101	-91
-59	-1
+1	+33

ACCESSIBILITY SHIFTS

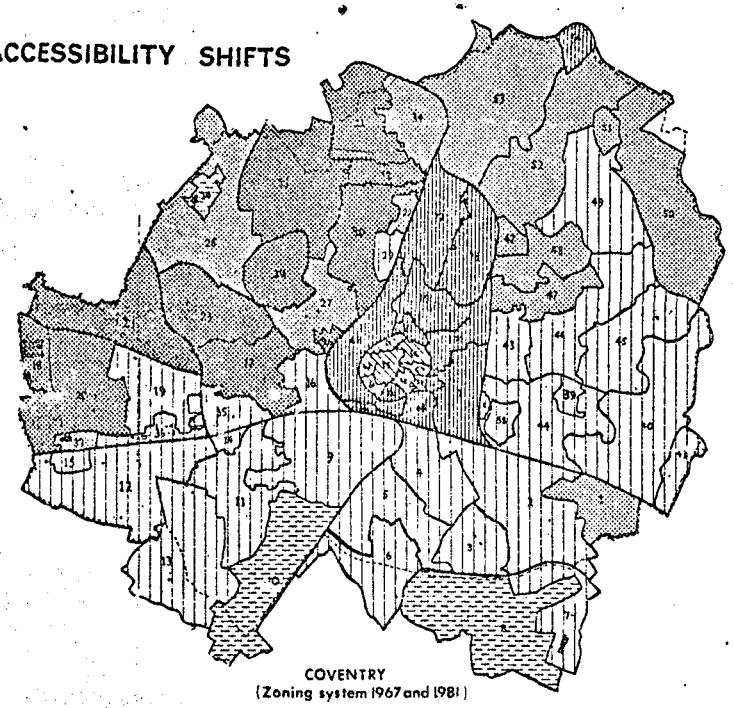


COVENTRY
(Zoning system 1967 and 1981)

POINT PRICING
TRIP DIFFERENCES

	-345
-142	-131
-93	-38
-32	-1
+1	+43

ACCESSIBILITY SHIFTS

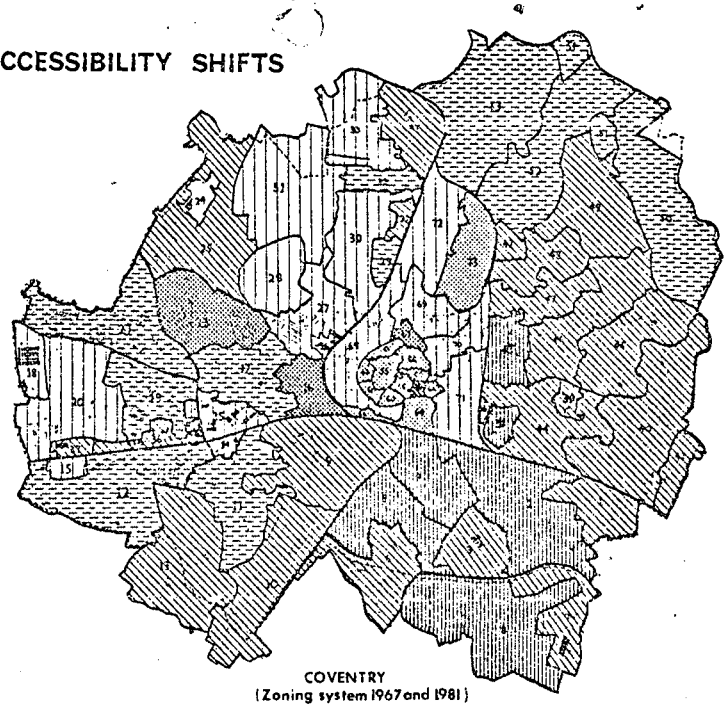


COVENTRY
(Zoning system 1967 and 1981)

PARKING (55D)
GENERALISED COST CHANGES

+25970 +21365
+19676 +16556
+11238 +8805
+6253 +72
-282 -2942
-3900 -13817

ACCESSIBILITY SHIFTS

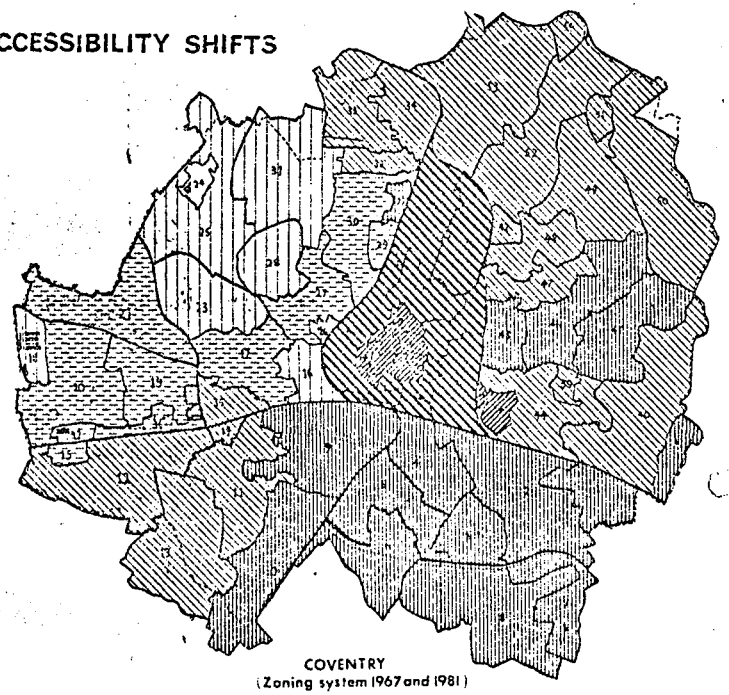


COVENTRY
(Zoning system 1967 and 1981)

CORDON (40D)
GENERALISED COST CHANGES

+26721 +16664
+15588 +10959
+10279 +7773
+6768 +16
-797 -3624
-5123 -8664

ACCESSIBILITY SHIFTS

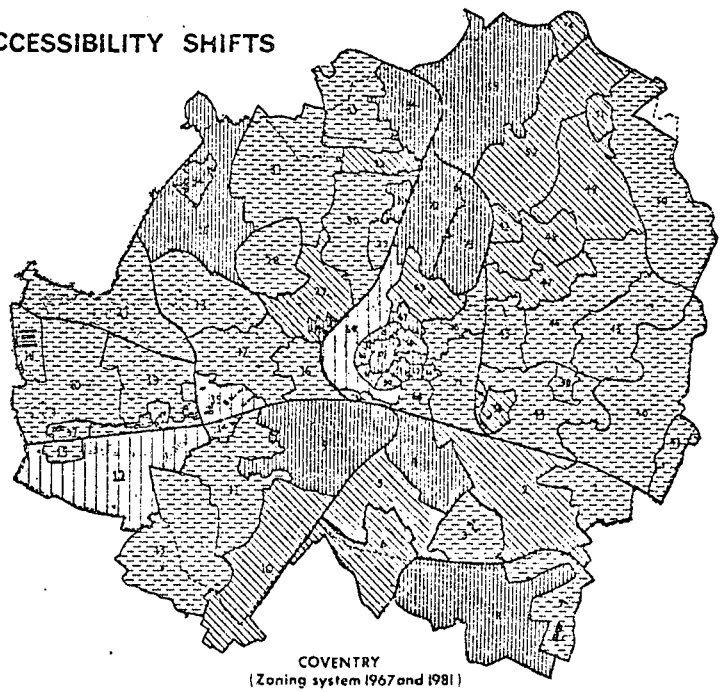


COVENTRY
(Zoning system 1967 and 1981)

SUPPLEMENTARY LICENCING (100D)
GENERALISED COST CHANGES

+55174 +44965
+40230 +34388
+31946 +23545
+22547 +15941
+14764 +7545
+6684 +1322

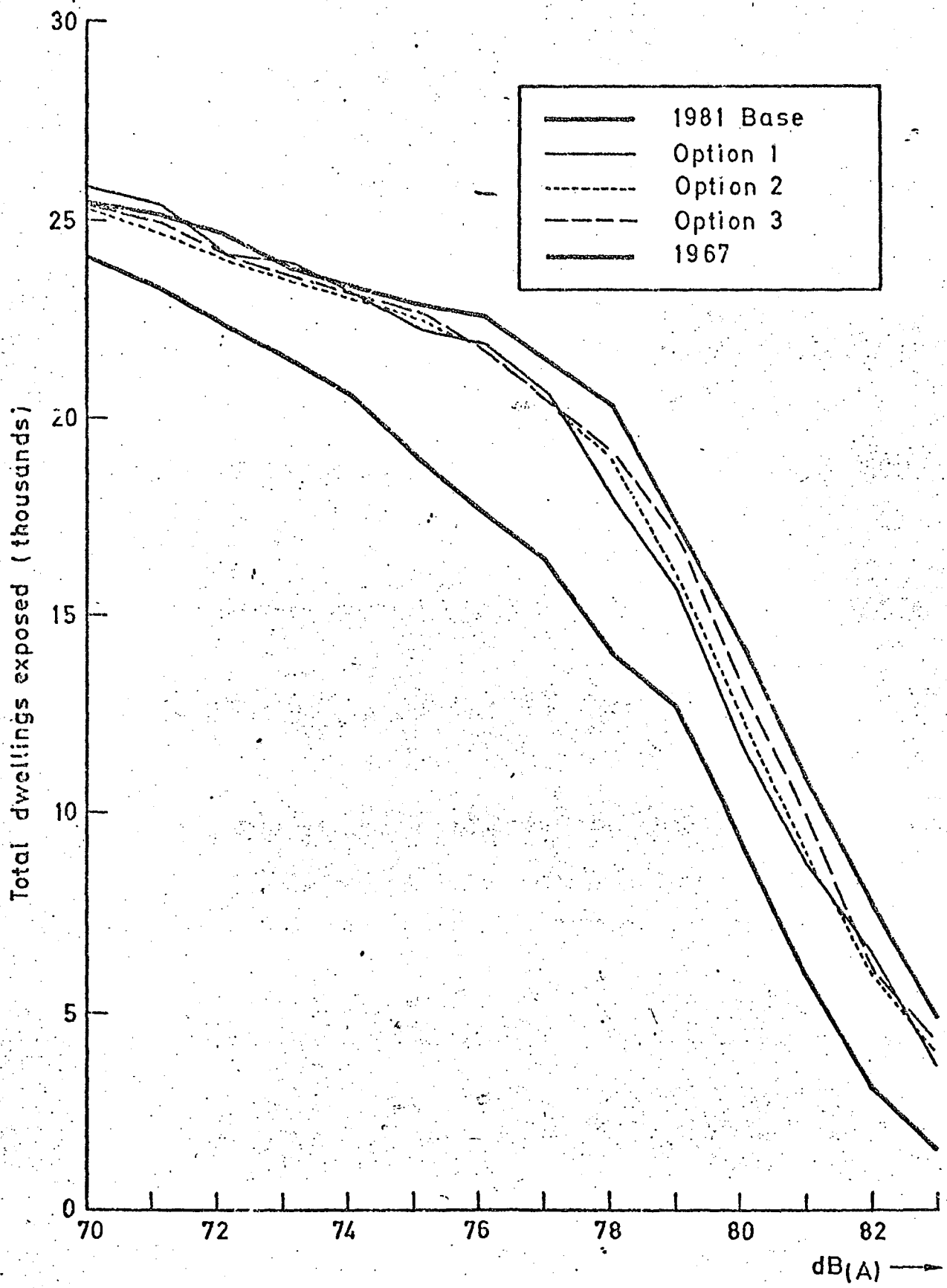
ACCESSIBILITY SHIFTS



COVENTRY
(Zoning system 1967 and 1981)

POINT PRICING
GENERALISED COST CHANGES

+29314 +20900
+19796 +14851
+14314 +6169
+3792 +3745



Total dwellings exposed to given noise levels plotted against average L_{10}, 06.00 to 24.00 hours

Fig. 30: FROM THE COVENTRY TRANSPORTATION STUDY GROUP REPORT

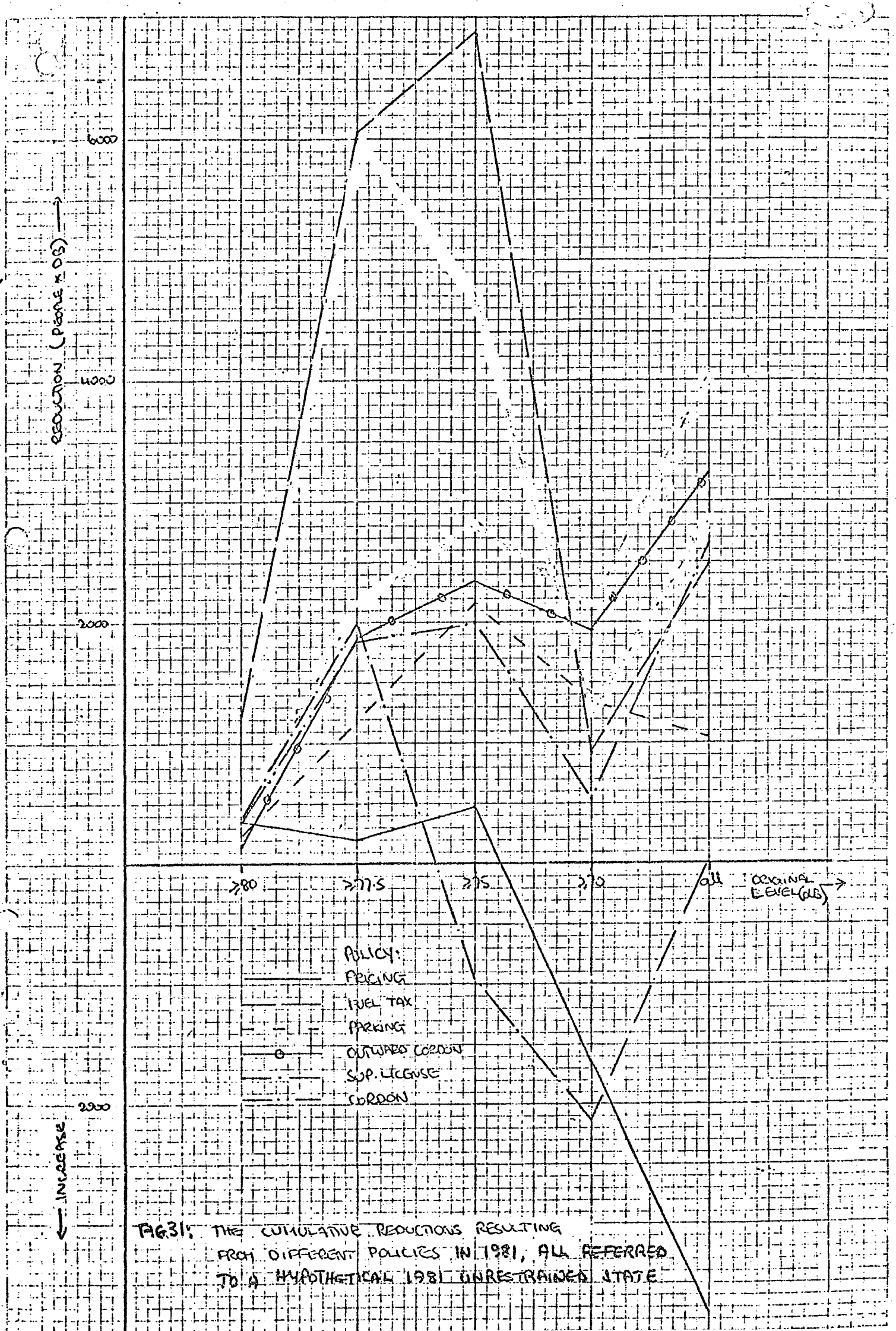


FIG 31: THE CUMULATIVE REDUCTIONS RESULTING FROM DIFFERENT POLICIES IN 1981, ALL REFERRED TO A HYPOTHETICAL 1981 UNRESTRAINED STATE

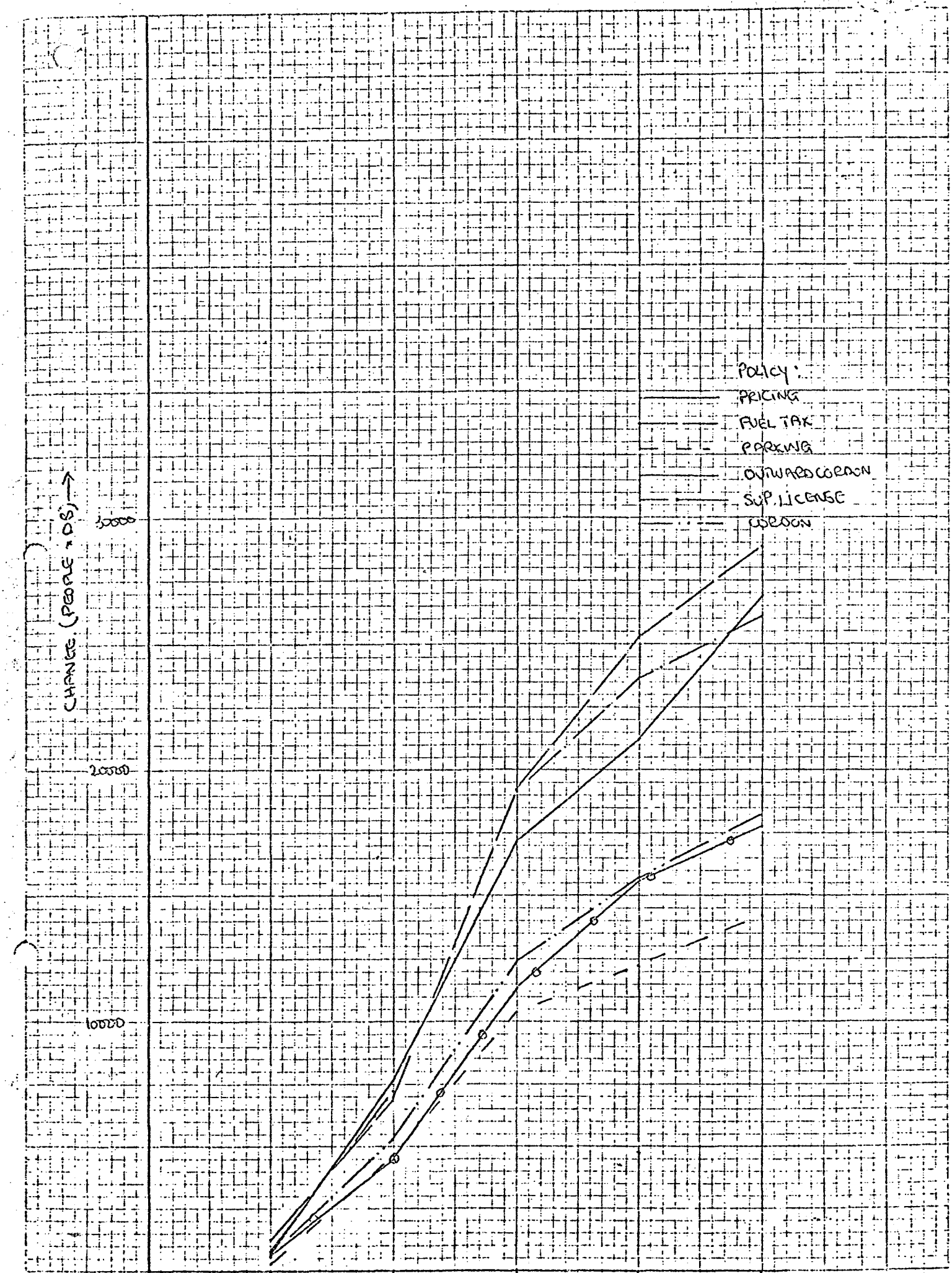


FIG 32: THE TOTAL CHANGES RESULTING FROM DIFFERENT POLICIES IN 1981, REFERRED TO A HYPOTHETICAL UNRESTRAINED 1981 STATE

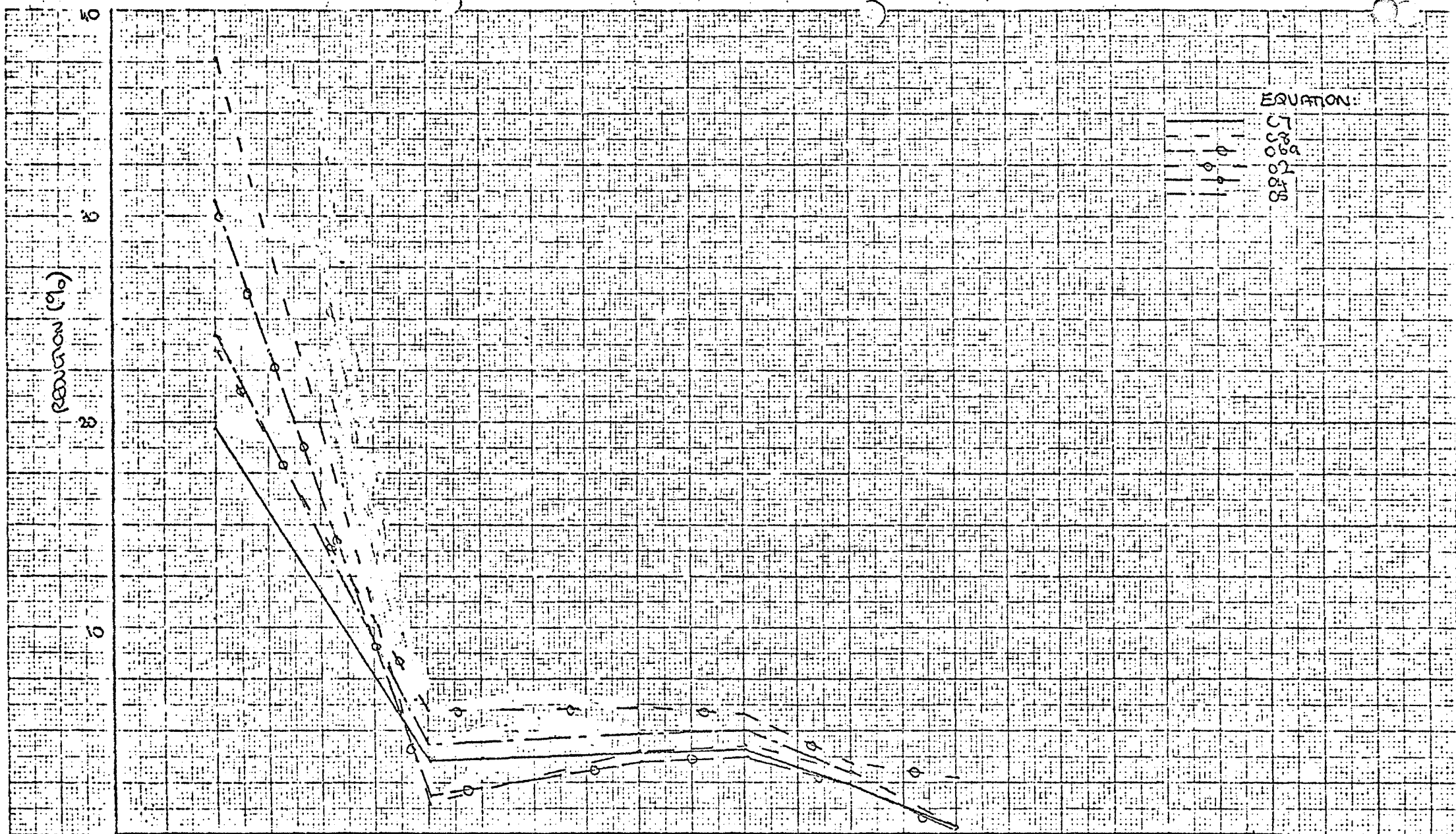


FIG. 33: THE REDUCTIONS EXPERIENCED BY THE MOST EXPOSED QUARTER OF THE POPULATION BETWEEN 1967 AND 1981 (UNRESTRAINED)

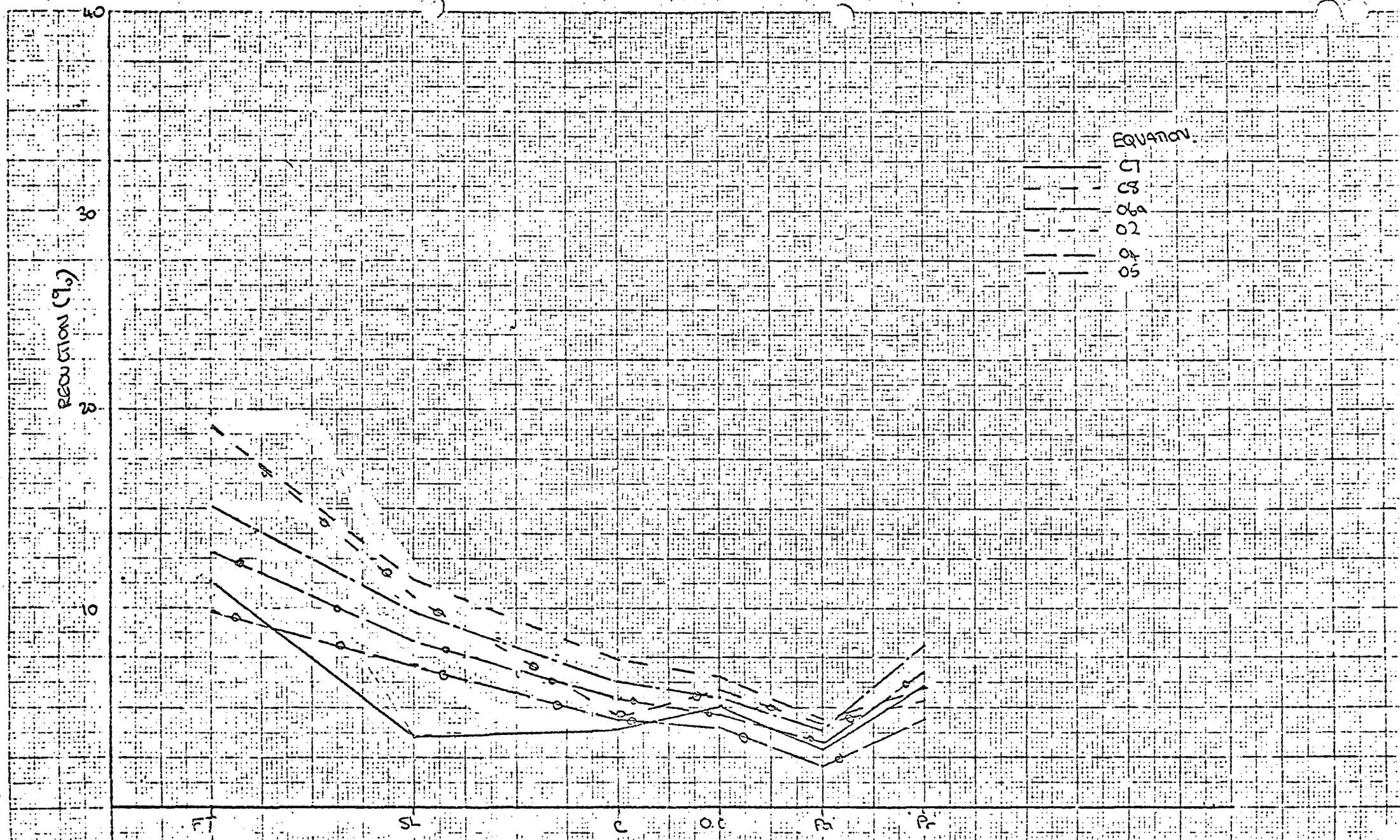


FIG 34. THE REDUCTIONS EXPERIENCED BY THE SECOND MOST EXPOSED QUARTER OF THE POPULATION BETWEEN 1967 AND 1981 UNRESTRAINED STATES.

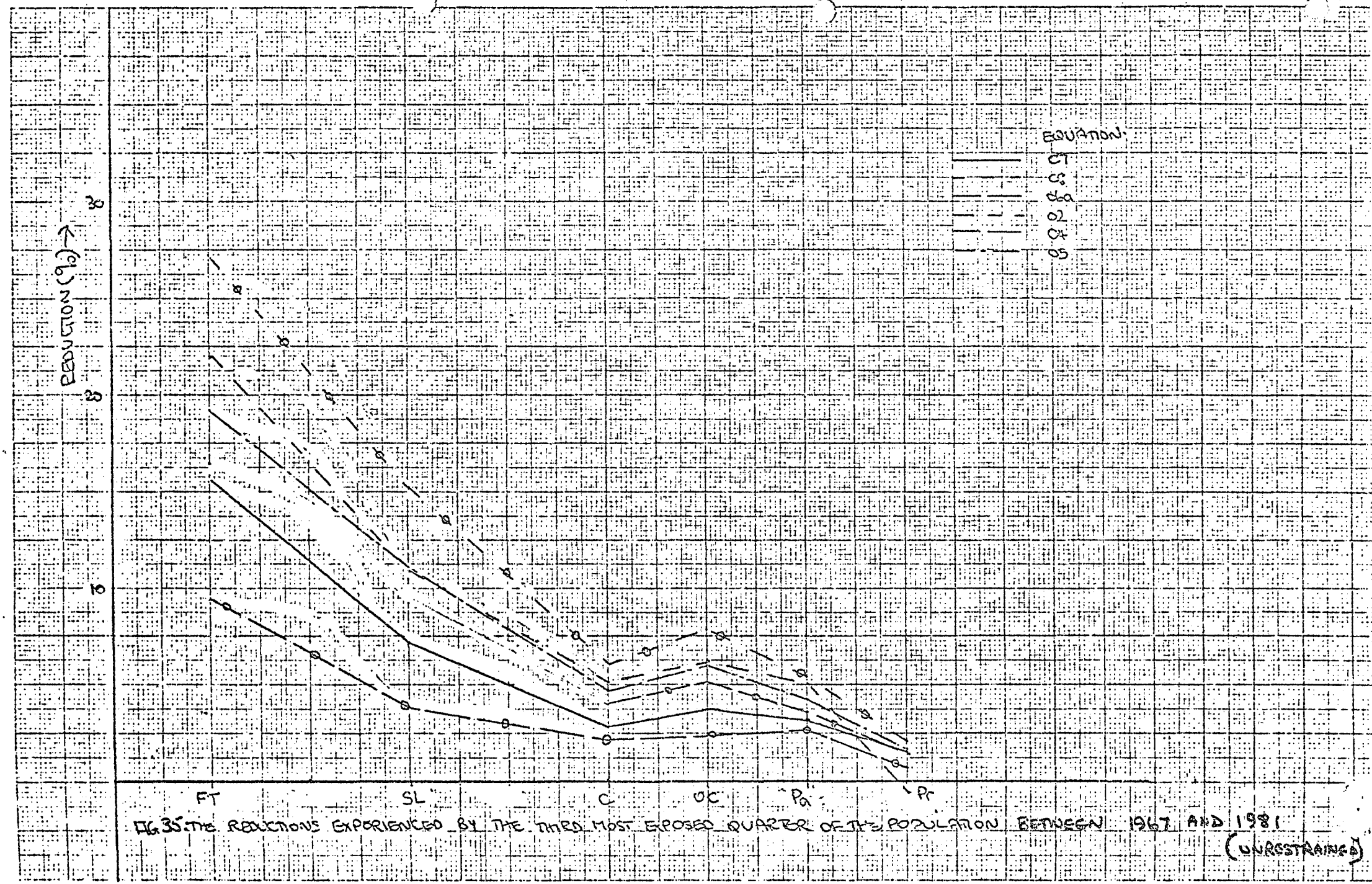


FIG. 35. THE REDUCTIONS EXPERIENCED BY THE THIRD MOST EXPOSED QUARTER OF THE POPULATION BETWEEN 1967 AND 1981 (UNRESTRAINED)

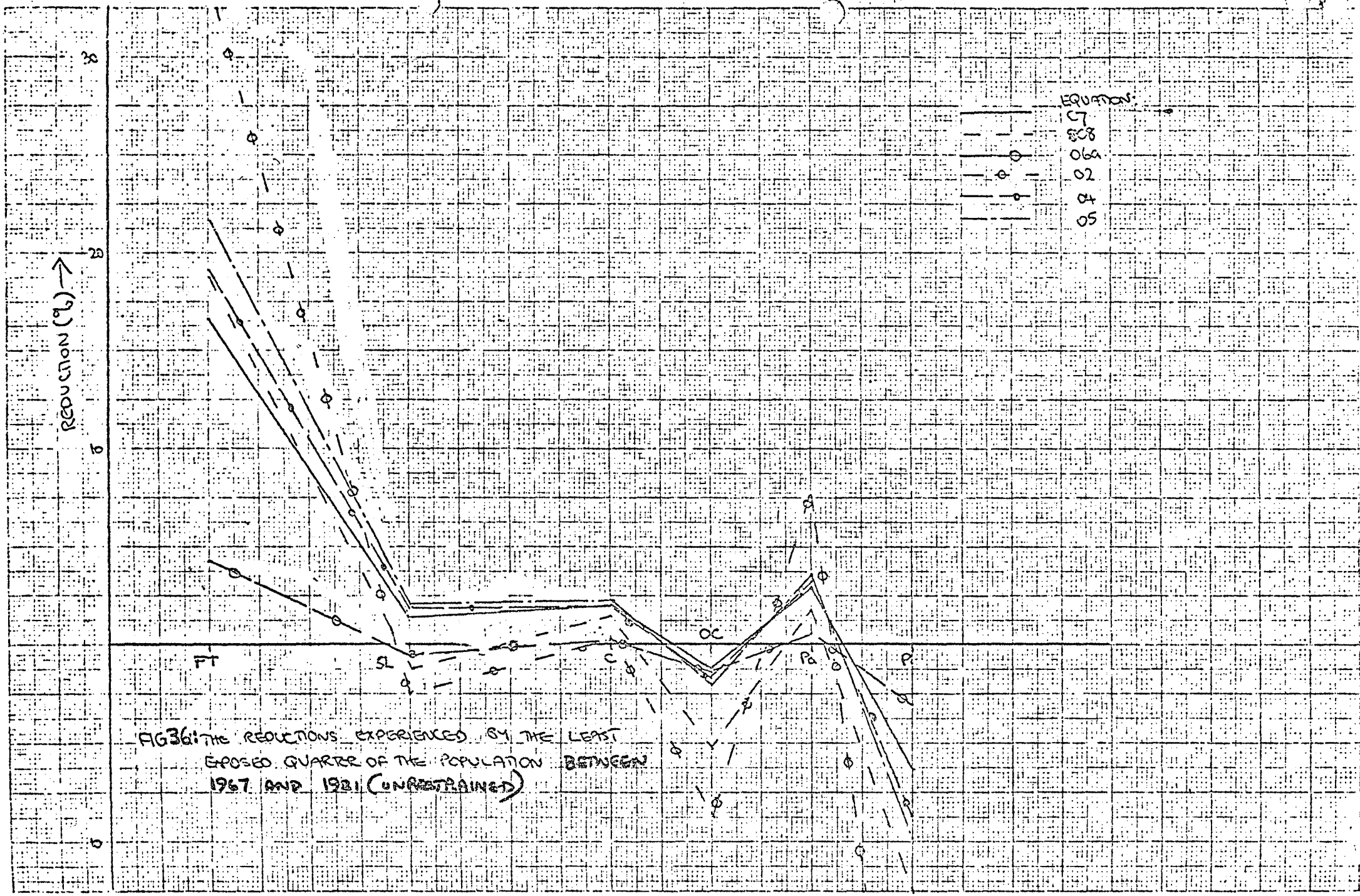


FIG36: THE REDUCTIONS EXPERIENCED BY THE LEAST EXPOSED QUARTER OF THE POPULATION BETWEEN 1967 AND 1981 (UNRESTRAINED)

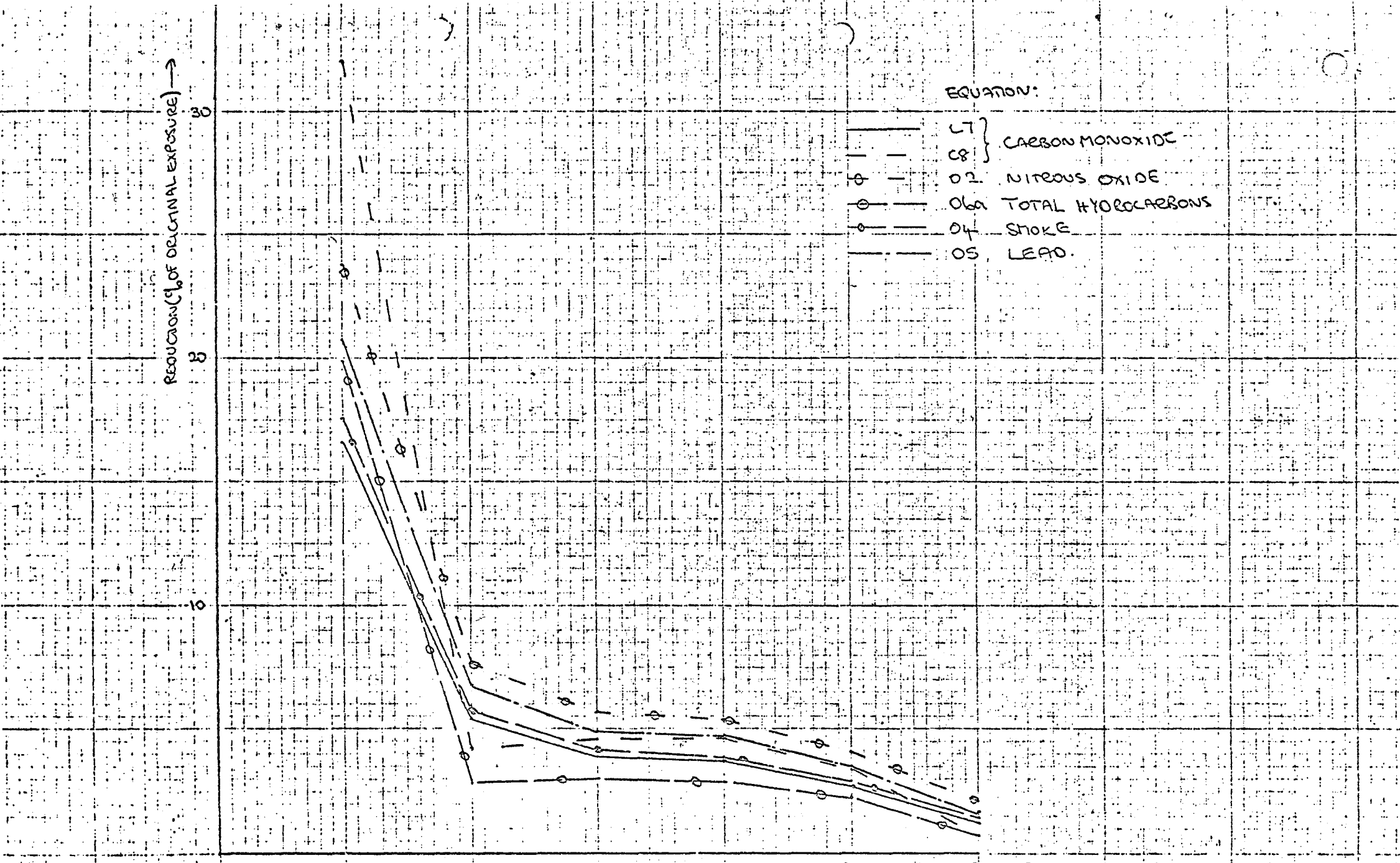


FIG 37: MEAN REDUCTION EXPERIENCED BY WHOLE POPULATION BETWEEN 1967 AND 1981 (UNRESTRAINED)

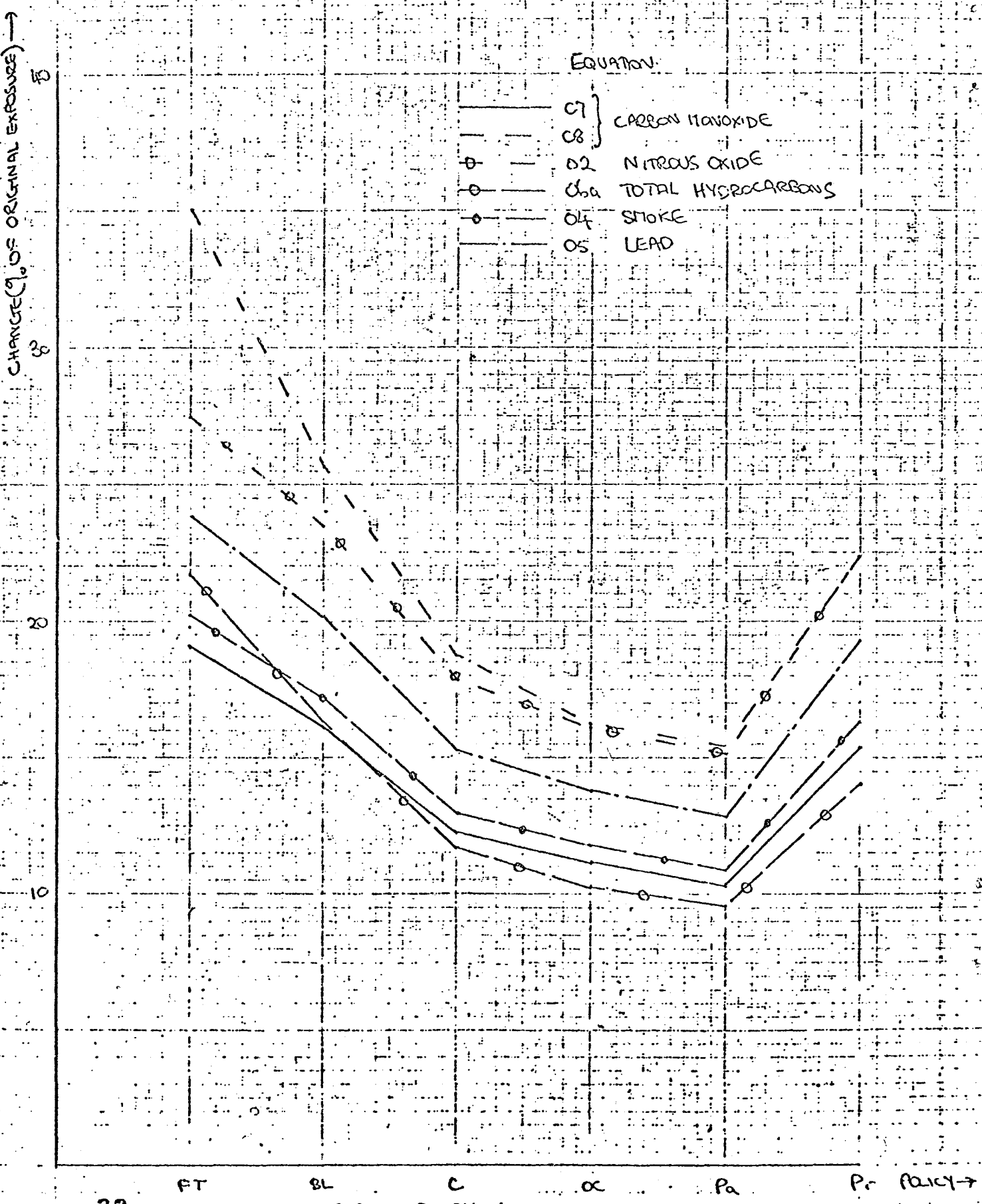


FIG 38: MEAN CHANGE EXPERIENCED BY WHOLE POPULATION BETWEEN 1967 AND 1981 (UNRESTRAINED)

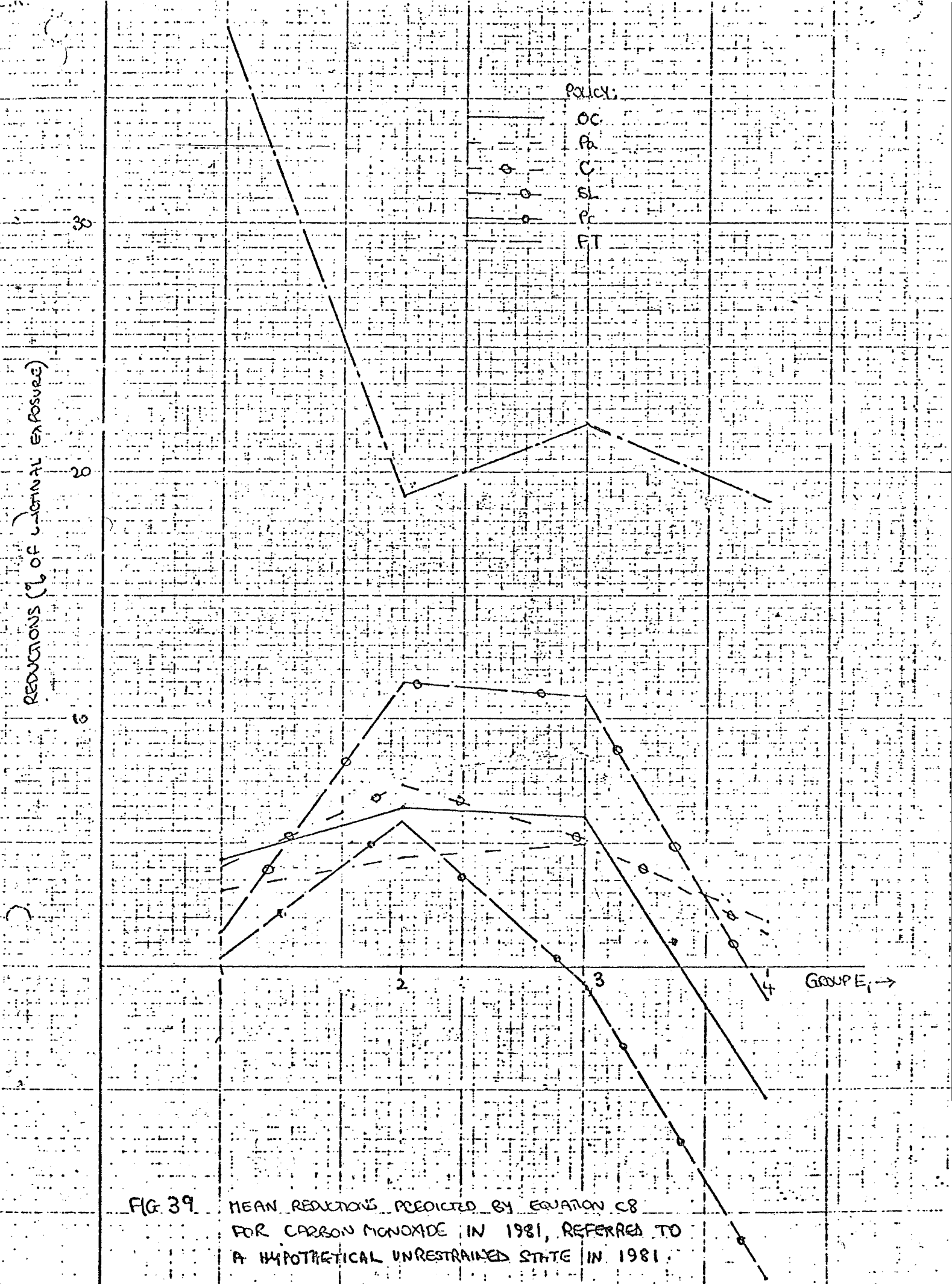


FIG 39. MEAN REDUCTIONS PREDICTED BY EQUATION C8 FOR CARBON MONOXIDE IN 1981, REFERRED TO A HYPOTHETICAL UNRESTRAINED STATE IN 1981.

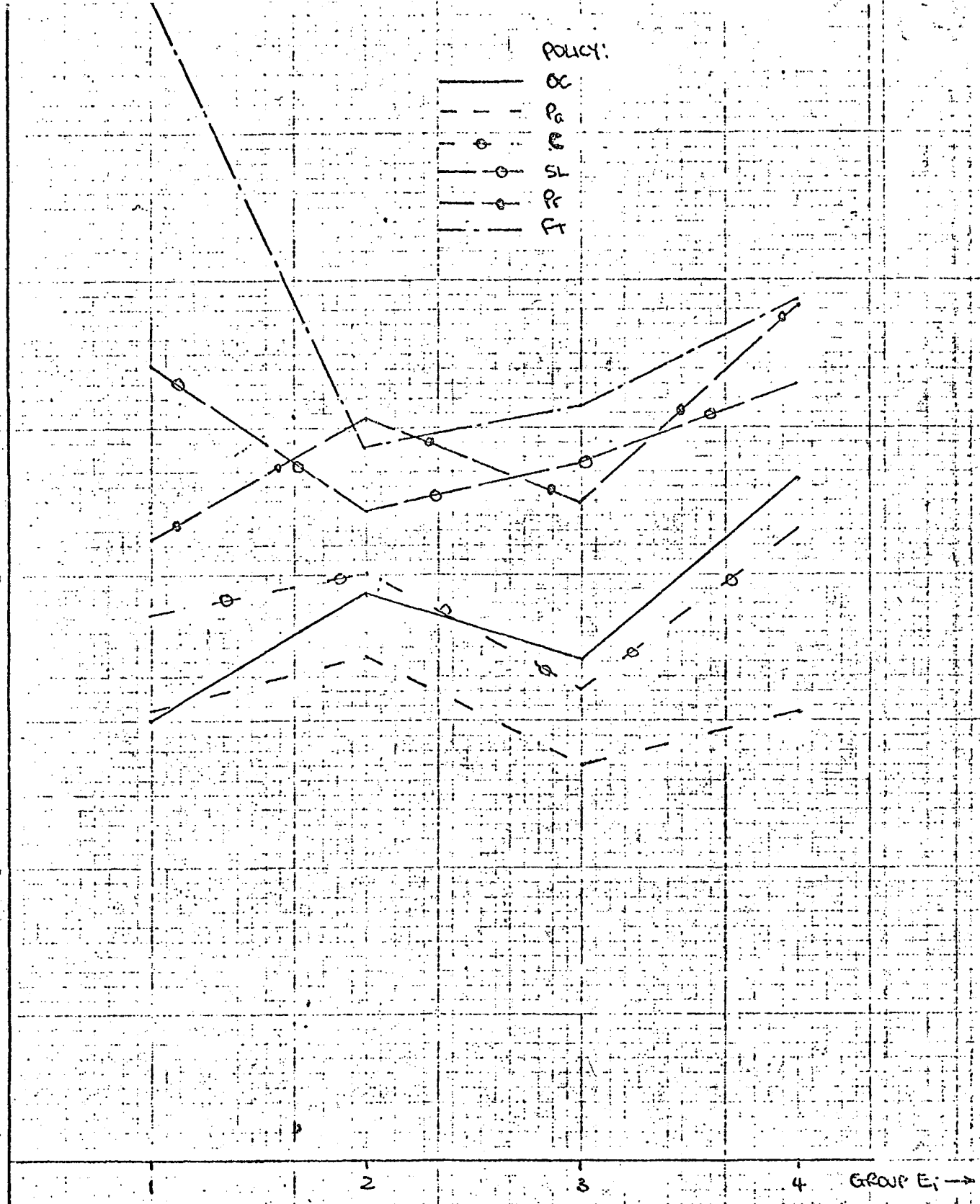


FIG 40: MEAN CHANGES PREDICTED BY EQUATION C8 FOR DIFFERENT RESTRAINT POLICIES IN 1981, REFERRED TO A HYPOTHETICAL UNRESTRAINED STATE IN 1981

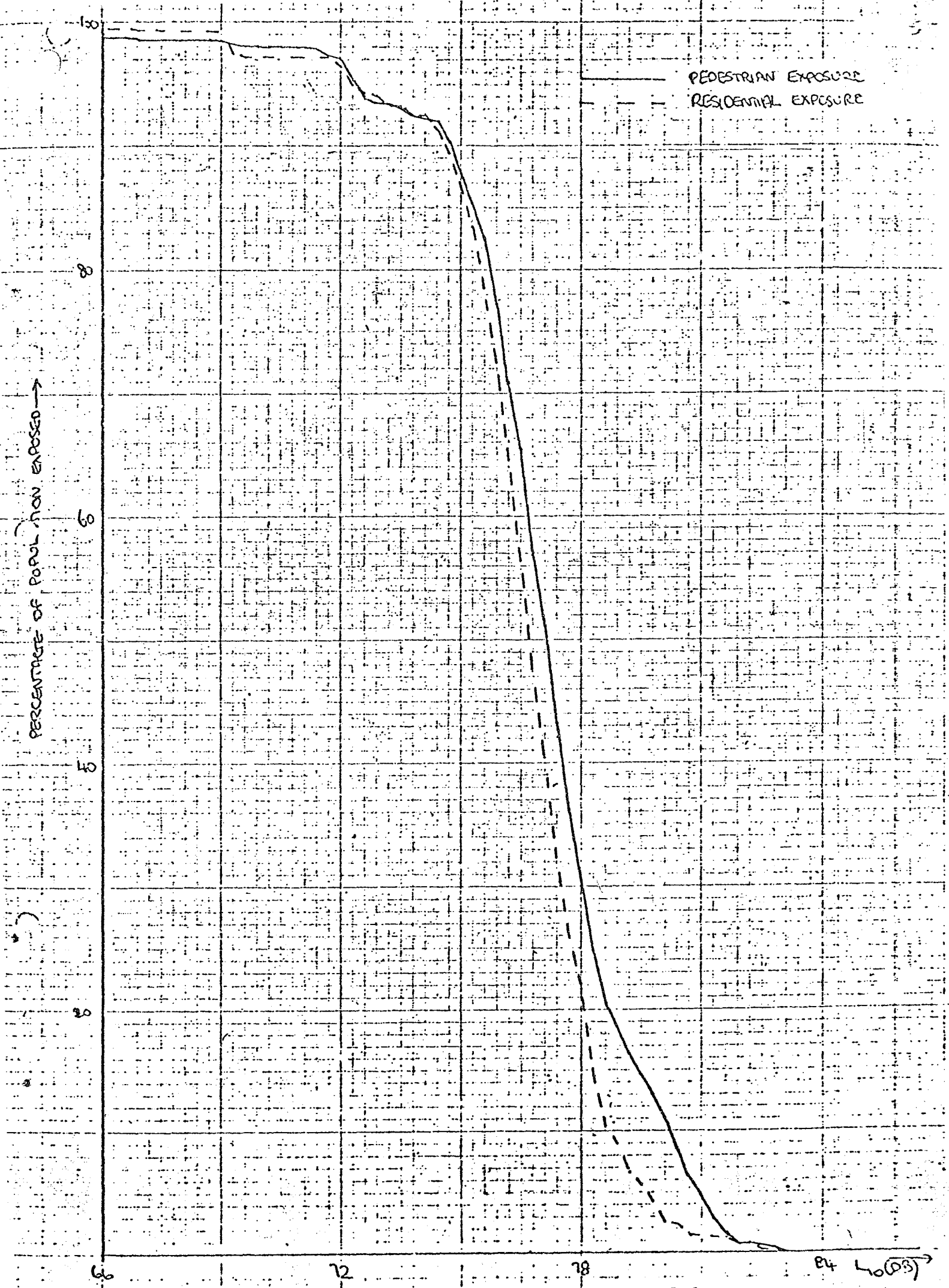


Fig 4.1 : THE EXPOSURE TO NOISE OF THE RESIDENTIAL AND PEDESTRIAN POPULATIONS IN THE UNRESTRAINED SITUATION.

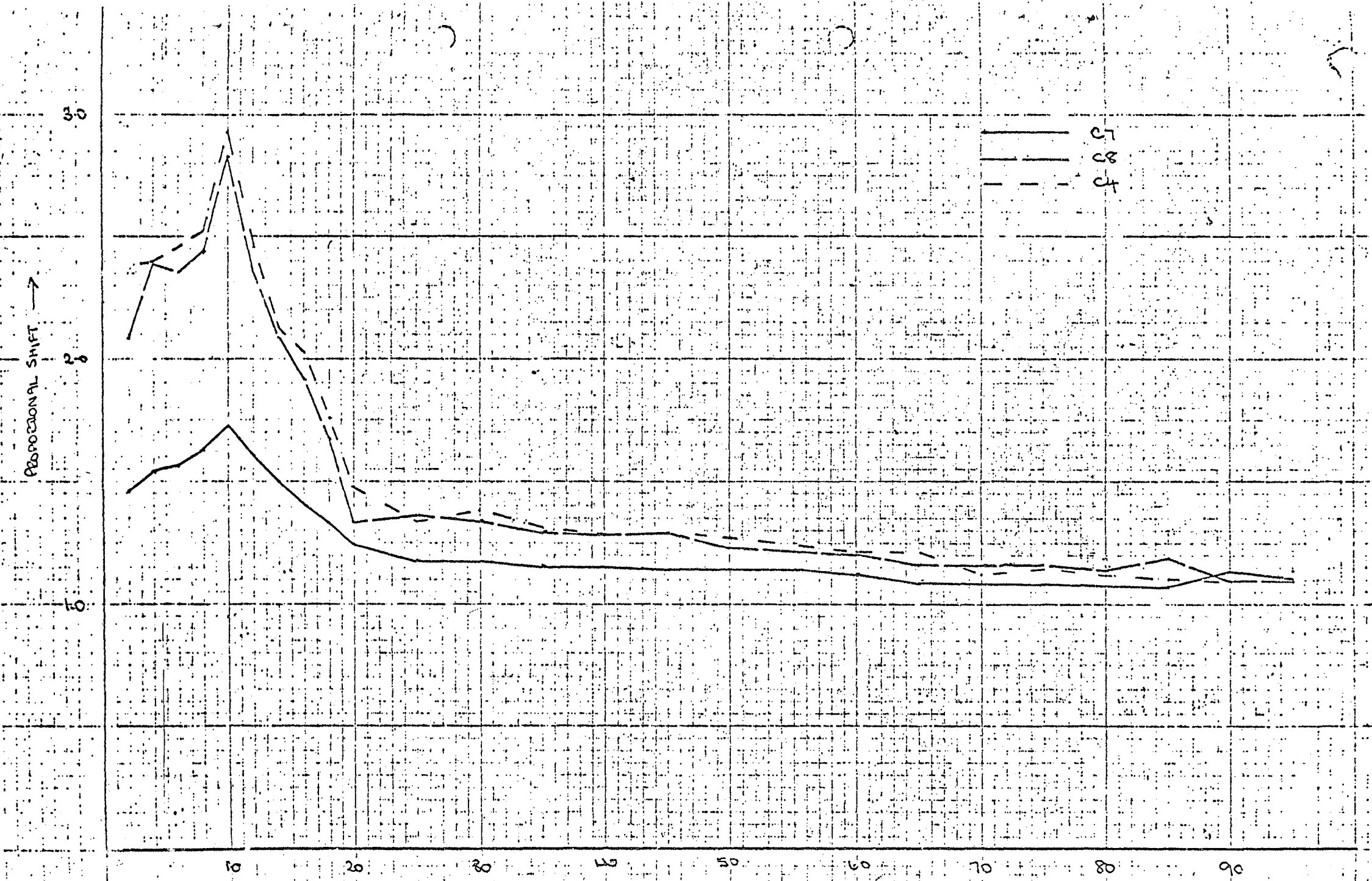


FIG 42 : THE EXPOSURE TO CARBON MONOXIDE OF THE PEDESTRIANS IS GREATER THAN THAT OF THE RESIDENTS.

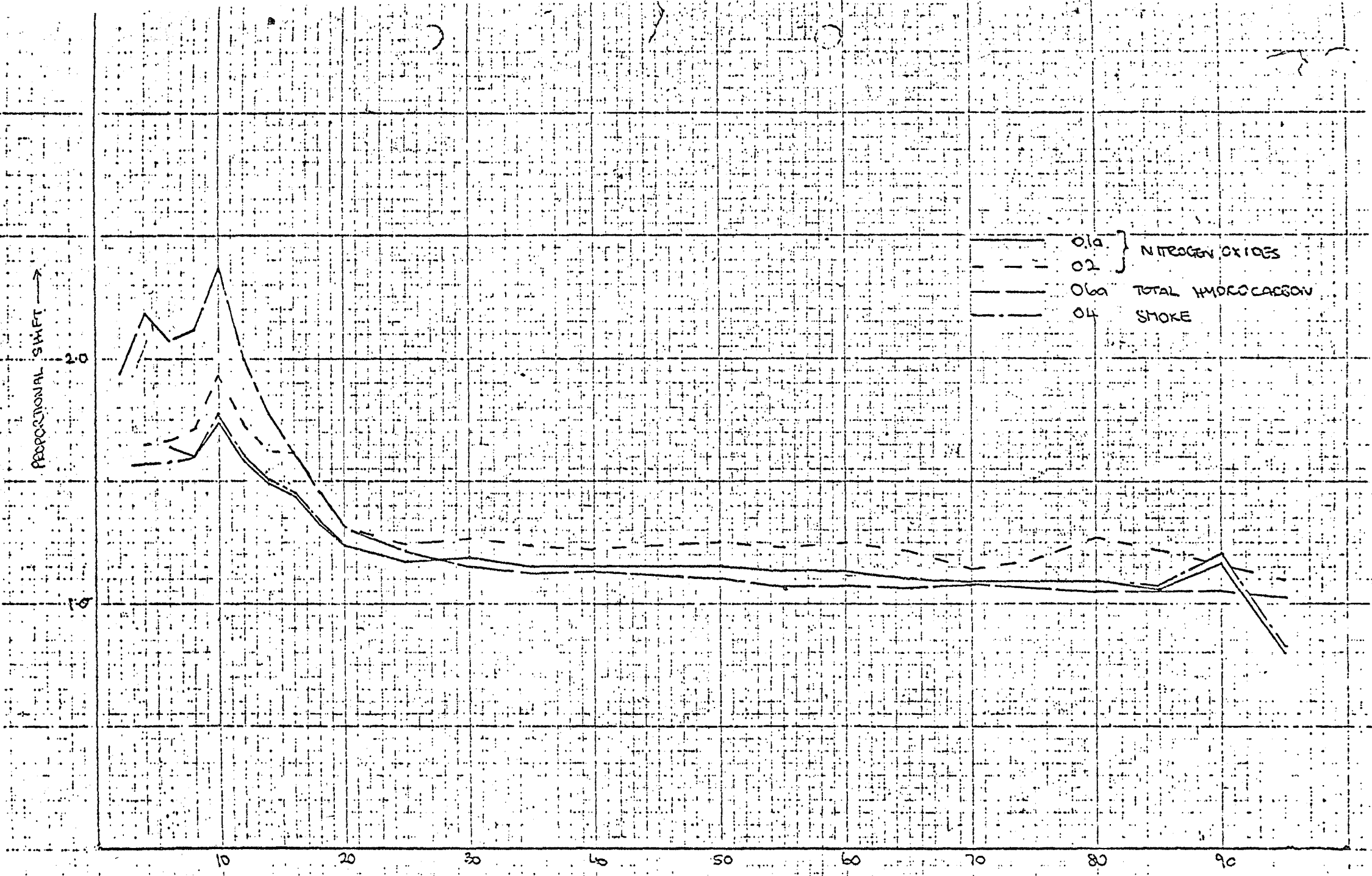


FIG 43 : PEDESTRIANS ARE MORE EXPOSED TO OTHER POLLUTANTS THAN RESIDENTS

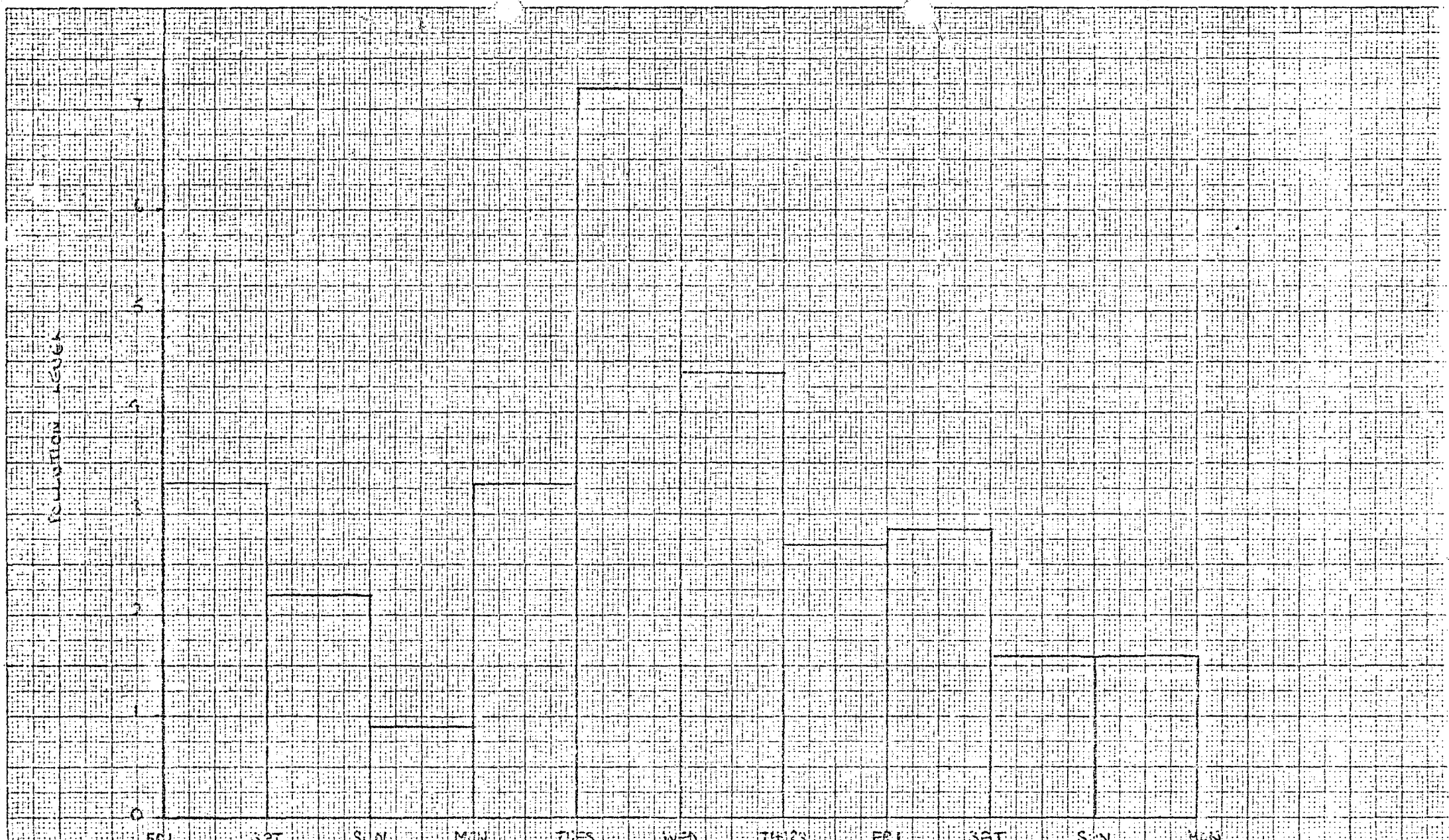


FIG COVENTRY INCREASING PARTICULATE LEAD MEASUREMENTS — 24 HOUR AVERAGE VALUES FROM 12 AM (16.11.73) TO 12 MN (26.11.73) AREA 2 : MAIN SITE : BUTTS ROAD